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MR. JOS. M. WILSON, President, in the chair.

VISCOSE AND VISCOID.*

BY CLAYTON BEADLE.

In August, 1894 (*Journal of the Franklin Institute*, Vol. CXXXVIII, No. 824), I had the honor of reading a paper before this Institute upon some new cellulose derivatives which had been discovered and partly worked out by my colleagues, Messrs. C. F. Cross and E. J. Bevan, and myself. Mr. Arthur D. Little, of Boston, took up the subject on this side of the water, and the samples which we showed you at that time were produced by him. Since then, we have added considerably to our knowledge of these derivatives. The basis of these products is a substance to which we

* Read by title.

have given the name "Viscose." Viscose is chemically cellulose xanthate, the preparation and constitution of which is fully explained and set forth in my previous paper (*vide ut supra*).

The dry regenerated cellulose obtained from the viscose solution we have named "Viscoid."

It is impossible, in a paper of this length, to give a history of all the work we have done in the last two years in connection with viscose; so I have chosen to confine myself to certain branches of the work, the description of which, I trust, will prove interesting to the members of the Institute.

MANUFACTURE OF ALKALI CELLULOSE.

In the manufacture of viscose on a large scale, we first endeavored to discover what materials could be utilized, and in the course of our work we found that any kind of cellulose could be used, provided that it was fairly pure. The fibers, however, should be very short indeed; the process depends as much upon the length of the fiber as upon the purity of the cellulose. As an instance of this, if raw cotton be used without any disintegration, it is almost impossible to mercerize it and convert it into viscose; but if the fiber be disintegrated so as to break up the ultimate fiber into pieces of about one-twentieth of the length of the original, the mercerization and conversion into viscose is rapid and complete. With regard to the purity of the fiber, bleached wood generally yields a better viscose than unbleached wood, but it is next to impossible to convert mechanical wood (*i. e.*, wood disintegrated by mechanical means, and containing a large amount of resin and other impurities) into viscose. The alkali cellulose often requires to be kept for several days before treatment with carbon bi-sulphide, but when the disintegration of the fiber is thorough and the mixture with caustic properly effected, the maturing of the alkali cellulose is almost unnecessary.

One great precaution, which at first we lost sight of, was to prepare the alkali cellulose without contact with the atmosphere.

This we discovered by analyzing a number of samples.

We found that on an average about 50 per cent. of the alkali had been carbonated during mercerization and thus rendered useless for the reaction. Alkali cellulose is converted by the action of the CO_2 of the atmosphere into sodium carbonate and cellulose without our knowing it. This change was the cause of a large number of failures, which necessitated conducting a series of trials under varying conditions, in which we determined the amount of alkali carbonated.

At last, we arrived at a method of producing the alkali cellulose by which only 5 per cent. to 10 per cent. of the total soda is converted into carbonate.

YIELD OF VISCOID.

A great deal of work has been done upon the amount of viscoid yielded by different celluloses. Pure cotton yields somewhat more than its own weight. This is due to a change in the cellulose molecule (*vide* Beadle, this *Journal*, Vol. CXXXVIII, No. 824). Wood, on the other hand, even when thoroughly bleached and pure, undergoes a considerable loss, which amounts often to 20 per cent. This is due to the formation of soluble products during mercerization.

We have followed this very carefully, and it appears that bleached wood pulp contains oxycellulose, which is largely dissolved by caustic soda. Under certain conditions the regenerated cellulose has no strength, as when films made from viscose solution are found to be rotten. Very great care has to be taken in the manufacture of viscose to insure that the regenerated cellulose is not injured by the treatment. A knowledge of this can be acquired only by experience, and those who are thoroughly acquainted with the manufacture of viscose can often tell at a glance, from the appearance of the alkali cellulose or the viscose solution, whether a satisfactory product will be obtained. These conditions are now well understood by us, so that we can insure that the cellulose is always regenerated in the proper physical condition required for the particular purpose to which it is to be applied.

PRODUCTION OF VENEERS.

Mention was made in my previous paper (*Journal of the Franklin Institute*, Vol. CXXXVIII, No. 824) of cutting pieces from the coagulum and annealing them under pressure for the production of sheets. This has been worked at on a larger scale. The viscose has been run into rectangular moulds, and the coagulation of the mass has been effected by exposure to a hot damp atmosphere. These masses, weighing from 250 to 400 pounds, have been dehydrated by exposing them to an atmosphere which is gradually raised in temperature. When the blocks have been sufficiently hardened they are cut into sheets about 24 x 18 inches, by a guillotine specially constructed for the purpose. By an automatic gear the bed on which the guillotine rested was made to travel forward at every stroke of the knife, and the amount of travel could be regulated at will, so that sheets of any thickness could be cut. By this means we were able to cut about twenty sheets per minute.

The sheets were deprived of the chemical by-products, and then submitted to heavy pressure, by means of which the cellulose hydrate was dehydrated down to a compact sheet of cellulose. We had a difficulty by this method in obtaining our dehydrated sheets free from structure. They had a tendency to split in laminæ. The fracture had every appearance of slaty cleavage (Beadle, *Chemical News*, London, Vol. LXX, p. 139), and the planes of cleavage were found always to be at right angles to the direction in which the pressure was applied. With thin sheets we had less trouble, and, I believe, the reason of this was that the sheet was thinner than the laminæ. In order to avoid this difficulty with thicker sheets, we were obliged to dehydrate the coagulum to a greater extent, by exposure to a hot atmosphere of steam before applying the pressure. The fact of pressure on the coagulum giving rise to slaty cleavage, prevented us from applying pressure for moulding solid articles from the coagulum. This is obvious when we take into consideration the fact that the dehydrated laminæ, formed on the outer surfaces by the first application of pressure, prevents

the egress of moisture from the interior, and, as it were, seals the interior from further dehydration. We found it next to impossible to mould articles of any thickness under pressure from the coagulum for this reason, even on the application of a pressure of several tons to the square inch. When, however, the sheets are almost dried by exposure to warm air, or by one of the processes described subsequently for the production of solids, they can be embossed and stamped into small articles, such as buttons, which are sufficiently structureless for all practical purposes.

When the sheets are completely dried they offer too great a resistance for moulding under pressure. Viscoid sheets can be produced by the above process in almost any color, either translucent or opaque, and they can be prepared in such a way that they are either soft and pliable, or stiff and horny like celluloid. Under pressure they can be embossed in various patterns.

PRODUCTION OF VISCOID.

For Use in Turning, etc.—Viscoid is prepared by coagulating the viscose in the same way as described above for the production of veneers or sheets, but the moulds are circular instead of rectangular. As might well be supposed, the difficulties of coagulating the viscose increase with the diameter of the cylinder. Great care has to be taken in the early stages to prevent the material from cracking. Immediately after coagulation takes place there is a considerable shrinkage, and unless the coagulation proceeds uniformly throughout the mass there is danger of it cracking. The time of coagulation increases with the diameter. The moulds in which the material is coagulated are specially constructed, and made of a material which is unaffected by the viscose, and the interior surface has to be such that the coagulum does not adhere to it, otherwise it is sure to crack on shrinking. After setting, the solid cylinders of coagulum are removed from their moulds. At this stage they are elastic and pliable, somewhat like rubber, but have to be handled with great care. They consist of about 15 per cent. of

cellulose, 7 per cent. of chemical by-products, and 78 per cent. of water of hydration.

Washing.—They are next placed in water for the removal of the by-products. We have done much work to determine the best conditions, and the cheapest and most effective method for getting rid of the by-products.

When the cylinders of coagulum are placed vertically in tanks provided with false perforated bottoms and immersed in water, the by-products are found to diffuse out and creep down the sides of the coagulum and to accumulate in the space below the false bottom. This action is so perfect, that often, when the water is undisturbed, the top portion contains only a trace of by-products and the lower portion is heavily charged with them. The removal of by-products is accelerated by the use of hot water. We find that the time required for the removal of the by-products varies as the square of the diameter of the coagulum. During washing, the coagulum undergoes a further shrinkage, so that when the washing is complete the coagulum contains about 20 per cent. of cellulose.

Drying.—The washed coagulum is next removed from the tanks and dehydrated or dried. The dehydration of the coagulum has presented us with some very interesting problems, which we have to a large extent solved. When the washed material is exposed to the air, it gradually contracts and loses weight, and this goes on until it is finally deprived of moisture, and nothing is left but the dry viscoid. We found it difficult to ensure that the material should retain its proper shape on drying. With "rack" or air drying at from 90° to 110° F., a solid cylinder remains flat at the ends, provided that the length is four times that of the diameter. If it is less than this, it has a tendency to become concave on the ends, and it becomes more concave up to a certain point as the length diminishes in proportion to the diameter. The sides of a solid cylinder have a tendency sometimes to become convex in proportion as the ends become concave. Unless drying is uniform, a cylinder of 1½ inches diameter and less, will bend less towards the driest side. With larger cylinders this is not so notice-

able. When cylinders are placed upon a rack that is not perforated, the top end contracts and dries the most rapidly, so that the cylinder becomes tapered towards the top. When the rack is perforated so as to allow of the free passage of air, the cylinder is sometimes found to be smallest at the bottom. Sometimes the cylinders are irregular in diameter or warped in final drying. During the process of drying, the coagulum is in a semi-plastic state, and, when the drying is uneven, is under considerable stress. The viscoid is caused to flow in the direction to relieve the stress, so that when finally dried and rigid, it is found to have assumed its original shape. It generally, however, leaves some marks of its temporary distortion. The time of drying, as far as our determinations have gone, varies as the square of its diameter.

When hot air is used, the rate of drying cannot be increased beyond a certain degree without serious injury to the solid. The solid, by constant exposure to hot air, becomes skin-dried, whilst the interior remains comparatively moist. The outer dried skin offers a great resistance to the passage of further moisture, and so the drying is very much retarded. If, under these conditions, the moisture is able to escape from the interior, the exterior being dry, and consequently rigid, offers great resistance to the contraction of the interior, and the consequence is that fracture often takes place. If the drying be not quite so rapid as to produce fracture, the interior is under tremendous stress, and when the cylinder is cut in section, cleavage often takes place in the direction of the length of the cylinder. When, however, the drying is conducted much slower, the moisture, which is always tending to pass from the wetter to the drier portions, finds a way of escape, and is removed from the surface by the atmosphere. We have been able to overcome these difficulties, and the product obtained is almost free from structure. The washed or unwashed coagulum has a natural inclination to contract when surrounded by a hot medium, even when the same has no drying capacity whatever. The rate of contraction increases with the temperature; thus, a coagulum contain-

ing 10 per cent. of cellulose will rapidly contract to about half its bulk on immersion in boiling water. When heated in this way there is no indication of case-hardening. There is a limit, however, to this contraction. We tried the effect of saturated steam at different pressures upon cylinders of washed coagulum, which contained about 15 per cent. of cellulose. The pressure was varied from 3 to 8 atmospheres; the time of exposure was one hour in each case. The average contraction was about 25 per cent. The experiments go to show that there is little or no difference between the 3 atmospheres or 8 atmospheres on the amount of contraction. As the diameter increases, the rate of contraction diminishes. The next set of trials were made to determine what effect time had upon the shrinkage in an atmosphere of saturated steam at 4 atmospheres. Taking the original weight as 100, after one hour's treatment, the weight became 82·9.

After two hours, the weight became	74·5
" three " " " "	65·7
" four " " " "	63·0

The above was on a piece of washed coagulum, containing about 15 per cent. of cellulose. We next took some unwashed coagulum, containing about 11 per cent. of cellulose, and suspended it in an atmosphere of saturated steam at 4 atmospheres. It lost 44·8 per cent. during the first hour; 14·7 during the second hour. Therefore, it had contracted during the two hours' treatment to 40·5 per cent. of its original weight. A receptacle was placed immediately beneath the coagulum to catch the by-products, which were found to be recovered without dilution. With blocks of double the diameter of the above, *i.e.*, 75 millimeters, the weight after two hours' treatment was 56·6 per cent. of the original. The effect of saturated steam is to produce a rapid contraction of the coagulum, if it contains from 10 to 15 per cent. of cellulose, and this contraction is rapid until a concentration of about 20 per cent. of cellulose is reached. By a prolonged treatment in saturated steam the coagulum gradually contracts until it contains about 25 per cent. of cellulose, beyond which point it does not alter.

IVORY-COLORED VISCOID.

Ordinary viscose has about the color and consistency of molasses, and yields a viscoid which has the general appearance of horn. We set to work to produce viscoid in imitation of ivory, and whilst doing this we discovered a new combination of viscose, which gave rise to a creamy white solution. This was found to last longer in the liquid form than the ordinary viscose. On drying down, it yielded a product which is a very fair substitute for ivory. It has a specific gravity of 1·8 to 1·85. We had several sets of billiard balls turned from this, and they were found to play very well, indeed. The angle, however, at which the balls left each other after striking was somewhat less than that of ivory balls. With the plain viscoid balls, which have a specific gravity of 1·5, the angle is greater than that of ivory, and we believe it possible to mix these two compositions in such a way that both the specific gravity and the angle at which they leave each other after striking resemble that of ivory. This "ivory" viscoid has been used for various articles, such as acorns for blind-cords, knife-handles, brush-backs, etc.

Viscoid for Electrical Work.—The plain viscoid was carefully tested to determine its insulating properties. It is about equal to vulcanized fiber for insulating purposes. It appears that if great care is taken to thoroughly remove the last traces of by-products, and to well season the viscoid, the insulating properties can be made much superior to vulcanized fiber. Cellulose, when completely deprived of moisture, is almost a perfect insulator, and its insulation diminishes as the hygroscopic moisture increases. Viscoid will probably replace vulcanized fiber to a large extent for electrical work, but at present it is very much inferior to vulcanite. It is likely that we shall find some means of improving it, so that it may be made to replace that substance.

Black Viscoid.—We next set to work to prepare an ebony-black viscoid, and after about six months' work we have obtained a uniform black viscoid, which in some respects appears to be superior to the plain substance. The ebony

viscoid will probably have a greater range of utility than any of the other products we have obtained. A jet black is preferable to white or any color for machine-tool handles, etc.

Blue Viscoid.—We have obtained a somewhat more expensive product very much resembling *lapis lazuli.* This is very nice for turning and carving, and takes a very high polish, and looks very well when made into fancy articles, such as umbrella and walking-stick handles.

Various Colors.—We have now got viscoid in a large variety of colors and shades, and have also succeeded in producing grained and mottled effects, which have a very pretty appearance when turned and polished. We see no reason why viscoid should not be used in place of celluloid for many purposes. Some samples have been kept two or three years and they do not discolor. Keeping the viscoid for a long time appears rather to improve it than otherwise.

PAPER SIZING.

Mr. Little mentioned this application of viscose in his paper (*Journal of the Franklin Institute*, Vol. CXXXVIII, No. 824). Viscose is now being extensively used in paper mills for this purpose. It does not size the paper in the sense that rosin does, although when viscose is used a large proportion of the rosin can be dispensed with. It is added to the beater, and a chemical substance is afterwards added which precipitates the cellulose among the fibers as a flocculent mass. The effect that it has upon the paper is, of course, dependent upon the amount used. It strengthens the paper from 30 to 100 per cent., and the paper produced with viscose, besides being much stronger, is also harder, has a better "feel" and rattle, and admits of a much better surface when calendered. It also assists in the retention of clay, and prevents the loss of short fibers which, as a rule, pass through the wire cloth of the machine. It therefore gives a larger output to the machine. It is chiefly used in the manufacture of "wrappings" and bag papers, but it is coming into use also for news and other papers. Where additional strength is not required, it

enables the paper-maker to use a lower-class and weaker fibrous material, without prejudicing either the strength or quality of his paper. By this means it decreases the cost of production. The precipitation of the cellulose requires a great deal of skill. Unless care is taken to ensure the right conditions, and to add the precipitating agents in the right proportions, the cellulose is precipitated as a non-adhesive mass, which gives neither strength nor hardness to the paper. It is necessary to know exactly the conditions of working in each mill before good results can be ensured, but when once these are known and understood there is no difficulty in obtaining uniform results.

THE NATURE OF HYGROSCOPIC MOISTURE IN CELLULOSE.

The behavior of viscoid on drying in the mass opened up some very interesting problems. It appeared to throw light upon the hygroscopic moisture of celluloses. I had previously observed (*Nature*, Vol. XLIX, No. 457) that the cotton fiber, when deprived of moisture (either by drying in an air bath at 105° C., or in a desiccator over sulphuric acid) and exposed to the air, rose in temperature rapidly for about eight minutes. It reached a temperature of about 4½° F. above that of the atmosphere, where it remained nearly stationary for a few minutes. It then fell gradually, and after about seventy minutes' exposure it again reached the temperature of the surrounding atmosphere. I endeavored to find what connection this had with the rate at which bone-dry cotton fiber assumed its hygroscopic moisture. I found that cotton fiber took about seventy minutes, and by weighing the cotton at different intervals, and comparing the rate of gain in weight with the rate of increase in temperature, I was led to the conclusion that the two were closely connected. The same experiments were repeated with anhydrous viscoid which had been ground to a powder before drying. The viscoid first of all suddenly fell below the temperature of the atmosphere. It fell much slower than the cotton fiber, and even at the end of 160 minutes' exposure it was still about 3° above the atmospheric temperature. At this point it had only recovered about 90 per cent. of its hygroscopic moisture, and it only came to a con-

stant weight after about 210 minutes' exposure. By grinding viscoid to a much finer powder than was used for the above, and repeating the experiments, a much more regular curve was obtained, and the hygroscopic moisture was very much diminished; but the time required for the material to fall to the temperature of the atmosphere was not lessened. I took some cotton wool which I ground to a fine powder, and I found that although it took about sixty minutes to recover its hygroscopic moisture, it contained only about 4 per cent. instead of 7 per cent. moisture. All these experiments were repeated with similar results. From this it is evident that the hygroscopic moisture of a cellulose, whether amorphous or in the fibrous condition, is dependent not only upon the character of the cellulose itself, but also upon the extent to which the cellulose is disintegrated. This is contrary to accepted views on the subject. It is only when particles of viscoid are below a certain size that the hygroscopic moisture is materially diminished. It appears that the cellulose that composes the cell walls of the ultimate fiber is under certain stress when deprived of moisture, in the same way that lumps of viscoid are when they are dried, and that the amount of stress determines the amount of moisture that it will take up to relieve the stress. Cellulose expands when hydrated, and it appears that the hygroscopic moisture is really water of hydration of the cellulose, and that it tends to hydrate in proportion to the stress that exists in the anhydrous cellulose. This accounts for the fact that the smaller particles of viscoid contain less hygroscopic moisture than the larger; also, which is more marked, disintegrated cotton fiber contains much less hygroscopic moisture than when the fiber is left intact. I have prepared small particles of viscoid, which, when bone-dry, would fly to pieces on being scratched, like "Prince Rupert Drops;" but the same particles, on being placed in a damp atmosphere, swell somewhat and recover their strength.

Particles can, on the other hand, be prepared in such a way that they do not exhibit brittleness, and they expand to a much less degree on being placed in a moist atmosphere. The results all tend to the same conclusion, in my mind, as to the nature of hygroscopic moisture in cellulose.

COMPRESSED AIR FOR CITY AND SUBURBAN TRACTION.*

By Herman Haupt.

Although a considerable amount of compressed air literature has been given to the public during the last two years, there is still a want of information as to the efficiency and economy of air motors as compared with cable, electric and other systems, and statements are continually published in the columns of the daily press that exhibit ignorance of scientific facts and apprehension of imaginary dangers.

Compressed air motors have been in successful operation in France for many years, and they are now rapidly establishing themselves in public favor in the United States. They have been constructed and tested at Rome, New York, continuously for two years, in all conditions of weather, and have given satisfaction even at temperatures below zero. Several motors are now, and have been, running for some months on the One-hundred-and-twenty-fifth Street Railway, in the city of New York, in daily service, without having lost a trip and with great satisfaction to the public.

The attention of the writer was first directed to the use of compressed air for city service in 1879, when he was called upon to examine, test and report upon several motors that had been constructed under the supervision of Robert Hardie, and allowed to be run on a portion of the Second Avenue Surface Railway, at Harlem, in New York. These motors were tested for several weeks, and the results were entirely satisfactory; but all attempts to secure their introduction proved fruitless. There was so strong a prejudice against them, that the president of one of the city railroads in Philadelphia declared that he would not have such a motor on his road if it saved the whole cost of horse-power; that it would frighten every team on the street to see a car

* Read by title, November 18, 1896.

running without horses, and the company would be perpetually annoyed by lawsuits. Explanations proved useless, and efforts were abandoned.

After the far more objectionable and expensive cable and trolley systems had been introduced and had demonstrated that a car could be run without horses and without frightening teams, the writer renewed efforts to educate the public, and especially the profession, in regard to the superior merits of compressed air. A book was published, giving a description and comparative cost of all the systems known or used for city traction, based on similar conditions of service.

This was followed by a number of monographs on special points, and finally resulted in the formation of a syndicate to raise capital and organize a company under the title of the General Compressed Air Company. The services of Mr. Robert Hardie were secured as engineer, and a motor constructed at the Rome Locomotive Works, which proved entirely successful from the start, and has been examined, tested and favorably reported upon by engineers, experts and scientists from all parts of the United States without exception.

Very erroneous opinions have been and are yet entertained in regard to the power lost in compressing air, the frost produced in expansion, the danger of explosion, the reheating of dry and moist air, the cost of plant, the necessity for frequent renewals of air supply, the possible length of run, the loss by transmission of air to distant points, and other matters connected with the practical application of air as a motor-power.

That the subject of air motors may be intelligibly presented, it is necessary to state briefly some of the properties of air and the laws which govern its compression, expansion and distribution, also such of the properties of steam as enter into the consideration of the questions at issue.

PHYSICAL PROPERTIES OF AIR AND STEAM.

Air at a temperature of 32° F. requires 12·433 cubic feet to weigh 1 pound; at ordinary temperature about 13 feet.

The weight of steam at 212° is 26·4 cubic feet to the pound, or approximately, for rough calculation, 26 feet. *Specific heat*, or capacity for heat, varies with different substances, and it is a very important element in calculations in thermodynamics. Water, having the greatest capacity for heat, that is, having a capacity to retain the greatest number of heat units per pound, has been taken as the unit of specific heat. On this standard, the specific heat of air is ·2377, or approximately ·24.

The specific heat of steam is ·475, or approximately ·48, or double the specific heat of air. In other words, steam is half as heavy as air, but has double the capacity per pound for retaining heat.

If air be suddenly compressed to one-half its volume, the temperature will be raised 116°, and if suddenly expanded to double its volume the temperature will be reduced to the same extent.

Under high pressure a given increase of pressure will develop much less heat than at low pressure. For example, a given volume of air at atmospheric pressure, condensed suddenly to one-half by an increase of pressure of 15 pounds, would develop 116° of heat, while under a pressure of 25 atmospheres an increase of pressure of 1 atmosphere would raise the temperature only 16·7°.

A thermal unit, or unit of heat, is the quantity of heat that will raise the temperature of 1 pound of water 1°, and a thermal unit is the equivalent in work of 772 pounds raised 1 foot.

A horse-power is 33,000 pounds raised 1 foot in 1 minute.

Isothermal compression is compression without evolution of heat. If this were attainable in practice, as much energy could be utilized in the expansion of air as was expended in compression.

Adiabatic compression is compression with evolution of heat. By compression and intermediate cooling it is claimed that 80 per cent. efficiency may be obtained. Under old systems of compression the loss has been conceded to be 50 per cent. The capacity of air for holding moisture is affected by volume and temperature, but not by density. A

cubic foot of air will hold no more water at the same temperature under 133 atmospheres than under 1; consequently, when this air is expanded to original tension, 1 cubic foot will contain only $\frac{1}{133}$ part of the moisture that it had originally and should be too dry to form a deposit of ice at the exhaust even if not reheated. Only low pressures can contain sufficient vapor to cause trouble; but as air should always be reheated, for reasons that will be explained, the difficulty from frost is purely imaginary.

Absolute or theoretical zero is a point determined by theory 461° below the zero of Fahrenheit, from which temperature must be estimated in problems connected with expansion of elastic fluids, the volumes being in proportion to the temperatures from absolute zero. This datum will be found essential in considering the question of reheating.

Latent heat is the heat that disappears or becomes latent in change of form, as from a solid to a fluid, or from a fluid to a vapor, and which reappears by condensation when the original condition is resumed.

In the liquefaction of ice 142·5 units of heat per pound become latent, and in the conversion of water into steam 966 units; so that the latent heat of water from ice is 142·5 units, and of steam 966°.

The specific heat of ice is ·50, so that the number of thermal units in 1 pound of steam at 212°, measured from absolute zero, will be $(461 + 32) \times \cdot 50 + 142 \cdot 5 + 180 + 966 = 1{,}535$ units.

An apology for these explanations and definitions seems to be required, as they apparently assume a want of information on the part of the reader, but there seems to be a necessity for explanations to remove the ignorance and prejudice that are almost universal. Even in technical journals, articles have appeared from the pens of gentlemen of high scientific reputation advocating the reheating of *dry* air to increase its power, and giving plans of apparatus for the accomplishment of this object. It will be shown that to double the power of dry air by an application of heat is practically impossible, and that it is only by an admixture of vapor that satisfactory results can be secured, yet this

demonstration could not be given without furnishing the data which it required.

AIR COMPRESSORS.

The use of compressed air for the operation of rock drills and for other purposes has become so extensive that it has led to great improvements in compressors, and several companies are now engaged in their manufacture who will furnish plants at moderate prices and guarantee results. Among these can be named the South Norwalk Iron Works Company, the Ingersoll Sargeant Drill Company and the Rand Drill Company. The best results are secured by repeated compressions with intermediate cooling, and large plants should always consist of a number of units, so that repairs to one will not affect the remainder, and the number in use at one time can be regulated by the demands of the traffic.

The experience gained by numerous tests, extending over a period of years, has furnished positive and reliable data by which to determine the amount of free air, under compression, required for any given service under any ordinary conditions. If responsible manufacturers of compressors will agree to furnish the plant at a given price, with a guarantee to compress a given number of cubic feet of free air per minute, delivered in station reservoirs under a given pressure, with a coal consumption and horse-power within prescribed limits, all elements of uncertainty as to cost of power seem to be removed; and this is being done.

The improvements in compressors have greatly increased their efficiency and extended the use of compressed air. In the primitive types an efficiency of 50 per cent. only could be secured; now 80 per cent. is claimed, while the ability to transmit power by this agency to long distances without serious loss, and to concentrate many small powers into a general reservoir will permit many water-powers to be utilized that would otherwise be worthless, and secure economies not offered by any other system.

The sudden compression of air is attended with a great evolution of heat. To compress two volumes of air into

one, as previously stated, will raise the temperature 116°; but it is a remarkable and valuable property of air and other elastic fluid, that under high pressures a given increase requires less power and develops less heat than under low pressures.

If, for example, it should be required to compress 3,600 cubic feet of free air per minute to a pressure of 500 pounds, the horse-power required would be 1,060 horse-power; if to 1,000 pounds the power would be 1,219 horse-power—a difference of 159 horse-power for 500 pounds; if to 1,500 pounds pressure, 1,288 horse-power, or a difference of 69 horse-power for 500 pounds; and if to 2,000 pounds, 1,339 horse-power, or a difference of only 51 horse-power to gain 500 pounds of additional pressure.

The power required to compress 1 cubic foot of free air is estimated as follows:

	Horse-power.
To 500 pounds pressure per minute	0·316
To 1,000 " " "	0·364
To 1,500 " " "	0·385
To 2,000 " " "	0·400

To which 10 per cent. allowance should be made in practice in allowing actual power for compressors.

Mr. E. Hill, the General Manager of the Norwalk Iron Works, gives absolute isothermal compression to 2,000 pounds per square inch per cubic foot of free air per minute, 0·315 horse-power, and the best possible in practice under the most favorable conditions, 0·378 horse-power. The computation of the writer gave 0·348 horse-power as the theoretical isothermal, but 0·45 should be allowed in practice. It is better to provide an excess of power than to suffer the inconvenience of a deficiency.

RE-HEATING.

A remarkable property of compressed air is that its efficiency can be doubled by re-heating. This is not theory; the fact has been confirmed by actual demonstration, both in Europe and America. It may appear incredible and contrary to well-known physical laws that the efficiency

of air can be doubled by simply passing it through a tank of hot water before admission to the motor cylinders, but such is the fact, and the reheating which doubles the power represents a consumption of coal only one-eighth of the amount required at the power station to produce the compression.

A direct test was made at Rome, on motor No. 100, in the presence of Capt. G. J. Fiebeger, of the U. S. Engineers, now Professor of Civil Engineering at West Point. The consumption of re-heated air from an average of many runs was 308 cubic feet per mile. When the re-heater was emptied of water, the volume of cold air required was 669 cubic feet per mile.

An explanation of this remarkable result will be given.

A comparison will be made between the results of reheating dry air to an extent sufficient to double its volume with and without the assistance of water, assuming the volume at 60° to be 300 cubic feet of free air, and that it is to be admitted to the motor cylinders under a pressure of 150 pounds to the square inch.

Assume, in the first place, that air at 60° is passed through a tank of water at 360°, giving a steam and air pressure of 150 pounds per square inch. The units of heat required to double the volume will now be determined.

The absolute temperature at 60° is $60 + 461 = 521°$.

The absolute temperature at 360° is $360 + 461 = 821°$, so that the air passing through water at 360° will be increased in volume, or under constant volume will be increased in pressure 63 per cent.

The thermal units required for the increase of temperature will be, 23 pounds of air raised 300°, specific heat of air being .24. Then $23 \times 300 \times .24 = 1{,}656$ units. The air has been increased in pressure 63 per cent., and to double the pressure by the addition of vapor or steam from the water will require the addition of 111 cubic feet of steam at atmospheric tension. That is, the 300 cubic feet of air at atmospheric tension has been increased to 489, and $489 + 111 = 600$. The 111 cubic feet of steam weighs 4.3 pounds, to secure which from water at 360° requires only the latent

heat, or 863 units. $863 \times 4{\cdot}3 = 3{,}711$, and adding the 1,656 units previously obtained, will give a total of 5,367 units.

Coal completely consumed will furnish 13,000 units per pound, petroleum 20,000 units per pound, and allowing for loss by imperfect combustion, 1 pound of coal or ½ pound of petroleum should furnish the fuel for re-heating at a cost of 2 mills for coal or 1¼ mills for crude petroleum, and 300 cubic feet of air thus re-heated should run an 8-ton motor much more than 1 mile.

To double the volume of air by the application of dry heat, the temperature must be double from absolute zero. At 60° observed temperature the absolute temperature would be $60 + 461 = 521°$, and the double would be 1,042°, and deducting 461° would leave the equivalent thermometric temperature 581°, a degree of heat that would burn out the lubricants and would be entirely inadmissible. In fact, it is stated in a recent work on compressed air by Mr. Frank Richards, that to double the power with dry air would require a temperature of about 800°, in consequence of the low specific heat of air and consequent rapid cooling.

As the air is supposed to be used expansively, so that the atmospheric tension is reached at the end of the piston stroke, the quantity of heat lost by expansion with an initial pressure of 10 atmospheres, or 150 pounds, would be 494°, which is nearly all that the heated air contained, so that if the admission could be at 581°, the exhaust would be 87°, without allowance for loss by radiation or conduction, and so much heat would be absorbed by the cylinder that the efficiency of the re-heated air would be greatly impaired.

On the other hand, if the air be passed through hot water, any vapor condensed in the cylinder yields its latent heat and steam, also acts as a lubricant.

Another striking comparison will be presented. Steam at 350° temperature and 150 pounds pressure, will, in cooling down to 212°, impart more than thirty times as much heat to the cylinders as an equal weight of air between the same temperatures.

The difference of temperature is 350 — 212 = 138°.
Specific heat of steam, ·475; air, ·24.

	Units.
1 pound of steam yields 138 × ·475	65·5
and of latent heat	966·0
Total heat from 1 pound of steam	1,031·5
1 pound of air reduced 138° yields 138 × ·24	33·12

One pound of steam carries as much heat as 31 pounds of air, and not only serves with little loss to maintain the cylinder and passages at a proper temperature, but, as previously stated, it also serves as a lubricant.

The reasonable conclusion is that it is practically impossible to heat dry air to an extent sufficient to double its power, and if practicable it would be inexpedient and the effect highly injurious.

The ideal re-heater would be a tank containing water at a temperature to furnish steam at the pressure of the air as used in the motor cylinders. The heat retained constant and uniform by cheap fuel, such as crude petroleum, and in winter the cars to be heated by water circulation from the same tank.

From tests made by him in 1879, the writer concluded that the average amount of water absorbed by the air and carried over in the form of steam was about 1 pound for 50 cubic feet of air. The accuracy of this result having been questioned, Mr. Hardie was requested to make a series of tests at Rome, the result of which established the fact that the quantity of water absorbed and carried over was dependent upon the temperature. At a high temperature in the water a comparatively small volume of air would suffice to evaporate a pound, and at a low temperature the volume of air was greatly increased.

The following table is interesting, showing the number of cubic feet of air at atmospheric tension required to absorb and carry over 1 pound of water in the form of steam or vapor:

Degrees F.	*Cubic Feet.*
At 321	35·2
At 300	42·5
At 296	43·3
At 274	48·5
At 259	95·2
At 210	159·0
At 190	238·0
At 182	229·0
At 170	221·0
At 164	459·0
At 158	493·0

RESERVOIRS.

The subject of reservoirs is one of the most important in connection with the construction of compressed air motors. The reservoir is the source of power in the motor, and upon its capacity and strength the possible length of run depends. Formerly, reservoirs were constructed of riveted boiler plates, and were capable of sustaining a pressure of from 300 to 600 pounds per square inch only. Consequently, a run of over 10 miles required so great an extension of capacity that room could be secured only by raising the floor to an inconvenient height above the rails. To secure long runs, with moderate reservoir capacity, high pressure is a necessity, and reservoirs are now manufactured, by a peculiar process, from solid ingots of mild steel, without a joint or weld, and which are capable of sustaining with safety a pressure of 2,000 pounds per square inch, the test, within the limits of elasticity, being carried to 4,000 pounds, leaving so large a factor of safety as to render rupture impossible.

It is proper to observe that the risk of rupture is not greater under a pressure of 2,000 pounds than it would be under 500 pounds, for the thickness of the shell would be four times as great with the higher pressure, and the strain per square inch of metal would be precisely the same in both cases.

Paradoxical as it may seem, it can be shown that a pressure of 2,000 pounds per square inch is actually more safe than a pressure of 500 pounds, notwithstanding the fact that newspaper scribblers, in the interest, apparently, of

rival systems, to create a prejudice against compressed air, magnify the risks of an explosion and the dangers to result therefrom.

Bear in mind that all reservoirs intended to carry 2,000 pounds are tested to 4,000 pounds, within elastic limits; consequently, the pressure could be increased 2,000 pounds more before the danger limit could be reached.

But if the pressure were 500 pounds the margin of safety would be the same, and the test would be to 1,000 pounds. Consequently, a variation of 500 pounds increase of pressure would reach the danger limit with the low-pressure reservoir, but would be 1,500 pounds below this limit with the high pressure. There can be no question of the sufficiency of the margin of safety.

But if, notwithstanding the theorizing upon the subject, the reservoirs should actually burst, would not the consequences be disastrous? The answer is no! A rent would be formed and the air would escape with a hissing noise. The material, unlike cast iron, is ductile and will stretch and pull apart and not fly in pieces.

The following extract from a letter from the manufacturers in Germany, addressed to the writer, will afford an explanation:

"Regarding the reservoirs, we put them to a test yesterday to state the elastic limit. It was reached at 3,500 pounds, but we went further in our experiments in order to demonstrate by practical test (as it has been demonstrated in hundreds of bursting tests of carbonic acid bottles) that these air bottles would not crack or fly to pieces, but that they would simply open when the breaking strain was reached (as was always the case with the carbonic acid bottles, when tested to bursting strain) and allow the contents to flow out, proving thereby that the handling of these bottles is in no way dangerous. We, therefore, think it advisable and safer for the future practical use of the bottles, not to test them, as we mutually agreed, till near to the bursting strain, but only till near to the elastic limits, because we are afraid that although they stand the test till near the bursting strain, the metal is somewhat weakened and, therefore, the practi-

cal use afterwards diminished. You will find the bottles somewhat lighter than ordered, and the question to decide for future deliveries will be whether you want the bottles as light as possible and use a storage pressure of 1,500 pounds per square inch, or if you prefer to make them somewhat heavier and use a storage pressure of 2,000 pounds per square inch. Please answer if you agree to the above, and we will send you the whole lot immediately. To-day we send you eight bottles, seven medium long and one short one, that you may, if you choose to do so, repeat the test to 3,500 pounds. As the fluctuations of the compressed air pressure, caused by the fluctuations in the atmospheric temperature are small when compared with the same fluctuations of the carbonic acid, we think it safe to test the air bottles only to the elastic limit, and use them with about half that pressure in practical work, as this way is safer than to test the bottles to the bursting strain and charge them only with one-third of that pressure afterwards in practical use."

Similar results have been indicated by tests in other localities, and it must be remembered that the rupture of a cylinder containing air produces effects that are widely different from those which result from the explosion of a steam boiler. When a boiler explodes, the volume of steam may be instantly increased more than a thousandfold by the conversion of water into steam by the reduction of pressure, the boiler is ruptured and pieces of iron and scalding water projected to great distances, while the rupture of an air cylinder allows a comparative moderate expansion of the contents, accompanied by a sensation of cold and not of heat.*

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* To illustrate more clearly the effect of the explosion of a steam boiler, let it be assumed that the dimensions of the boiler are 3 feet diameter and 12 feet long, containing 85 cubic feet, of which 70 cubic feet are water and 15 cubic feet of steam at a temperature of 350°.

The 70 cubic feet of water will weigh 4,375 pounds, and at 350° will contain 1,531,250 units of heat.

The 15 cubic feet of steam at 15 atmospheres will weigh 9 pounds and contain 10,602 units, and the whole contents of the boiler 1,541,870 units of heat.

Let x = quantity of water at 212° not converted into steam by the explo-

WEIGHT OF RESERVOIRS.

The weight of reservoirs is in proportion to the number of cubic feet of free air that they inclose, and that again is in proportion to the length of run, and is entirely independent both of diameter and pressure.

The truth of this position can be demonstrated rigidly, but a simple explanation will suffice to make it clear.

Suppose a reservoir of any diameter, say 1 foot, is under a pressure of 2,000 pounds per square inch, 1 foot in length of such reservoir will weigh a certain number of pounds.

Now, suppose the diameter should be reduced to one-half or 6 inches, the thickness of metal to resist the pressure would be one-half as great as formerly, and the circumference also one-half, consequently the weight per foot would be one-fourth; but to secure equal capacity the cylinder must be four times as long, and, therefore, the weight, with a given capacity, must be the same whatever the diameter.

Again, suppose the pressure should be reduced from 2,000 to 1,000 pounds per square inch, the weight to resist this pressure would be reduced one-half, but to contain the same quantity of free air the capacity must be doubled, and, consequently, the weight would be the same as before.

It follows, therefore, that whatever may be the diameter of the reservoir or the pressure per square inch, the weight of reservoir to enclose a given *weight* of air will be constant.

What then is the weight per cubic foot of interior capacity required to resist a pressure of 2,000 pounds per square inch, equivalent to 136 cubic feet of free air?

If 35,000 pounds be assumed as the elastic limit of the material, and one-half, or 17,500 pounds, as the maximum

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sion. Then $4,375 - x$ = water converted into steam at 212°. Latent heat, 966 units. Then $212 + (4,375 - x)\ 966 + 10,602 = 1,541,870$. From which $x = 3,600$ pounds, and $4,375 - 3,600 = 775$ pounds of water converted into steam by the explosion = 20,176 cubic feet, $20,176 + 225 = 20,401$ = cubic feet of steam liberated, and $20,401 \div 15 = 1,360$ times the original volume of steam which has been increased by the explosion.

strain upon the metal per square inch from an interior pressure of 2,000 pounds, then it will be found that the weight per cubic foot of interior capacity will be 115 pounds. The weight of the last importation of the German reservoirs was 106 pounds per cubic foot of interior capacity.

As the 115 pounds per cubic foot under 2,000 pounds pressure contain 136 cubic feet of free air compressed into 1 foot, the required weight of reservoir will be 0·856 pound for each cubic foot of free air that may be enclosed.

If, in addition, it should be assumed that 400 cubic feet of free air should be provided to run an 8-ton motor 1 mile, with sufficient allowance for contingencies, the weight of reservoir per mile run would be 338 pounds. This weight, it must be understood, applies to the motor only, and is the equivalent of 42 pounds per ton of motor weight. Trail cars will require only about one-third as much per ton.

[*To be concluded.*]

RESULTS OF THE WORKING OF TWO-CYLINDER COMPOUND LOCOMOTIVES ON AMERICAN RAILWAYS.

By John H. Cooper.

I have the pleasure of presenting in detail the following results obtained during the year 1896, in regard to the working of compound locomotives.

These data relate exclusively to comparisons of performance between two-cylinder compounds and simple engines, when alike in every respect except the compounding devices, and working under similar conditions.

Two-cylinder compound locomotives may be treated under three heads or types, which may be defined in general terms as follows:

(1) Those in which the intercepting valve is automatic and which cannot be run as a simple engine. This type is without a reducing valve.

(2) Those in which the intercepting valve is operated by steam, but is under the control of the engine-driver, and is provided with a reducing valve, which is automatic.

(3) Those in which the intercepting valve is operated by a rod connection from the cab, under control of the engine-driver, either by hand or by steam or by air; this type also has a reducing valve, which is automatic, allowing the engine to be run either simple or compound, at will.

These types will be found fully illustrated and described in the technical journals.

Should it be desirable to obtain the results of the working of other types of compounds, in order that the comparison shall be of value to railway men, the data must come from persons running them with simple engines of like size and type, under exactly the same conditions as has been done in the case of the two-cylinder compounds.

The simple engine constitutes the standard of cost and running expenses, and is, therefore, the measure for ascertaining the commercial value of the several systems.

Were this comparison obtained, there would be little difficulty in determining the relative value of every type of compound, providing the performances of the simple engines exhibit such a similarity of result as will admit of easy and correct equating.

The writer and his colleagues, who have aided him in obtaining the facts here presented, have been particularly requested to withhold names of persons, roads and locomotives for reasons best known to the parties furnishing the data. Whether authorities are given or not, they offer truth for authority, upon which they rest our case.

They have been careful in getting these results of performance that they should be derived solely from the official records, which are made by persons whose duty it is to furnish the facts of experience.

With these preliminary explanations we present extracts of performance sheets of twelve compound engines, having cylinders 21 and 31 x 24; also of a simple engine, which is an exact duplicate of the compounds, except that the cylinders are single expansion. This engine carried the

same steam-pressure as the compound, and worked under precisely the same conditions. It will be noticed that these reports are for May and June, 1894, being the last ones received, and were furnished after the engines had been in use more than a year.

EXTRACTS FROM PERFORMANCE SHEETS FOR THE MONTH OF MAY, 1894.

	Consolidation Compound.	*Consolidation Simple.*
Number of miles run in freight service	16,520	2,425
Cost per mile for oil and waste (cents)	0·34	0·33
Cost per mile for fuel (cents)	13·52	16·66
Number of miles run to one pint of valve oil .	53·02	86·61
Number of miles run to one pint of engine oil .	21·34	14·97
Pounds of coal per loaded freight car, mile . .	3·41	4·46
Number of miles run to one ton of coal	21·49	17·43

YOUGHIOGHENY AND HOCKING COAL USED.

Cost of fuel-wood per cord	$1 86
Cost of fuel-coal per ton	2 87

MONTH OF JUNE, 1894.

	Consolidation Compound.	*Consolidation Simple.*
Number of miles run in freight service	13,478	1,827
Cost per mile for oil and waste (cents)	0·34	0·42
Cost per mile for fuel (cents)	11·68	18·09
Number of miles run to one pint of valve oil .	63·07	39·72
Number of miles run to one pint of engine oil .	17·81	14·50
Number of miles run to one ton of coal	25·08	16·13
Pounds of coal per loaded freight car, mile .	3·43	4·30

YOUGHIOGHENY AND HOCKING COAL USED.

Cost of fuel-wood per cord	$1 86
Cost of fuel-coal per ton	2 87

From another source we make the following extracts:

"All conditions should be alike, save the compounding, and then the engines should be manned alike and have the same character of fuel, substantially the same loads, weather, etc. Further than this, the trial should be of sufficient length to carry it down to every-day work, and should cover the changing of engineers and firemen, as well as all the vicissitudes of weather and work. In no other way can we answer the criticisms or overcome the scepticism of many regarding the value of the compounding principle. We

must be able to show that we not only do save fuel, but that we do not have excessive repairs arising from the changes in machinery.

"It is of a trial of this character that I write, the compound engines being of the two-cylinder type. This paper is intended simply to show what these particular engines did, and not to demonstrate that other engines, or types, would or would not do just as well. The writer was able to cause this test from the fact that, in ordering a lot of engines, he had one ten-wheel passenger out of three, built on the same specifications, compounded, and two 'Consolidation' freight engines out of eighteen, on the same specifications, compounded. The weight of all these engines was the same, 126,000 pounds, without the tender, and they were delivered and put into service about the same time. The simple 'Consolidation' engines were 20 x 24-inch cylinders, while the compounds were 20⅝- and 29 x 24-inch. The cylinders of the ten-wheeled simple engines were 19 x 24 inches, while those of the compound were 19 and 27 x 24 inches. The 'Consolidations' were substantially duplicates of a large number of other engines of the same character, which, after some years' use, had been worked up to a very economical point. During the previous years, we had procured a ten-wheeled passenger engine, which had been changed, experimentally, until it had become unusually economical in fuel. This was the basis of the three new ten-wheeled engines, and they were found most excellent in their workings.

"The comparisons of the ten months' work of the passenger engines are shown in the following tables:

COMPARISON OF PASSENGER ENGINES.

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Two simple engines	107,885	564,995	5·23	6,263,654	11·086
One compound engine	48,100	254,204	5·17	2,097,911	8·252

"Saving, 2·834 pounds of coal per car-mile, or 25·56 per cent.

"The work of four simple and two compound freight engines for eleven months is shown, as follows:

SIMPLE ENGINES.

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Four engines, East End, 6 mos. .	81,226	1,335,045	16·43	8,252,533	6·132
Four engines, West End, 5 mos.	61,318	1,190,786	19·41	5,977,917	5·029
Total, 11 mos.	142,544	2,525,831	17·23	14,230,450	5·634

COMPOUND ENGINES

	Miles Run.	Car-Miles.	Average Cars Per Train.	Pounds Coal Consumed.	Pounds Coal Per Car-Mile.
Two engines, East End, 6 mos. .	27,682	495,050	17·88	2,454,142	4·957
Two engines, West End, 5 mos. .	31,550	712,291	22·57	2,667,505	3·746
Total, 11 mos.	59,232	1,207,341	20·38	5,121,647	4·242

"Saving, 1·392 pounds of coal per car-mile, or 24·70 per cent.

"Here we have a marked saving in a year's work. We believe the conditions were such that the test is of more value than were the first ones made, as it shows the every-day work of the compound engines compared with exactly the same simple engine under the usual working conditions. No tests can be fairer, and I have seen none of more value.

"I regret to state it, yet it is true, that there was at the start a universal prejudice against the compounds among the engineers and firemen. They were pronounced failures before they were set up, and long after they had shown their good qualities the unfavorable criticism continued. They 'would not start the train,' but they did it. They 'could not run up the long hills,' but somehow they did it quite as easily as the other engines. They 'could not pull within two or three cars of the other engines,' but a year's work shows they averaged larger trains, and in repeated cases, they have pulled as heavy trains as any engines on the road.

"But when they saw the compound passenger engine run the round trip with a tender of coal, and run easily 100 miles with one tank of water, they had to admit that there was some good in the new departure.

"It is our belief that this test of nearly a year in every-day work, with changing engineers and firemen, against exactly similar simple engines, doing the same work at the same time, is more valuable than any tests yet reported in this country, and demonstrated beyond a question the value of the compound principle in locomotive engines, in the matter of coal consumption.

"The importance of this is seen when it is known that the cost of fuel is about 10 per cent. of the whole cost of operating, and when we consider that the 32,000 locomotives in this country probably consume 30,000,000 tons of coal per annum.

"There is, however, another matter to be considered, and it is one that has rendered American engineers sceptical as to the real value of the compound engine; that is, one of repairs, as well as first cost. It stands to reason that the cost of maintaining three cylinders or four cylinders will be larger than the cost of maintaining two.

"I have a report of the repairs upon the engines under consideration from January 1 to June 30, 1891, a period of six months, while they were running together, and for six months of the time in which the consumption of coal is considered.

"Considering first the freight service, we find that the

Four simple engines in six months ran	76,827 miles.
Total cost of running repairs done	$1,312.66
Cost per mile run (cents)	1·70

"In the same time and over the same ground, the

Two compound engines ran	39,268 miles.
And the running repairs cost	$612.72
Or per mile (cents)	1·55

"Showing that for six months the compound ran more economically than the simple, as far as repairs are concerned. It is quite probable, however, that in another six

months this would be evened up, and the cost per mile would have likely been equal to that of the simple engines.

"When we consider that with cheap coal (say $1.50 per ton) the cost per engine mile for fuel is, for freight trains, about 7 cents per mile, and for passenger 4½ cents, we can see that a saving of even 20 per cent. in fuel means over 1 cent a mile, and that it cannot be outweighted by any reasonable, or I may say possible, increase of repairs, as but a small part of such repairs pertain to, or are affected by, the parts compounded.

"We believe this to have been a good practical test of the two-cylinder type of compound engines, and while no claim is made to perfection, it seems to have covered a sufficient length of time, amount of work and variety of climatic and other conditions, to have overcome the influence of any prejudices, or efforts for or against any particular engine or of any special skill on the part of any one man, that in a short run or experiment might have a marked effect."

From another source we quote:

"Where coal costs from $3.50 to $4 per ton, of course economy in the quantity consumed is a matter that is looked after.

"One of these two-cylinder locomotives has been running for about three years past, and the reports we have received from the officials of the railway company go to show that the saving in fuel, due to the compound system, has averaged about 17 per cent. comparing it with simple engines of the same type and capacity, doing practically the same work, and run on the same division.

"The saving of fuel in the case of the other four compounds on the same line which have been in service for about one year past, is said to be about the same—17 per cent.—as compared with the simple engines. No special tests or efforts have been made, so far as we know, in the matter of saving fuel; but the results are obtained from the monthly reports of fuel consumed by the locomotives on the line.

"The reports as to the cost of repairs of these compounds

indicate that they are little, if any, more than the simple engines, doing the same work on the same line.

"In the case of the other four compound locomotives, sent to another road, we have as yet received but little data as to their consumption of fuel. Some tests that were made, but continued for about ten days only, showed results that indicate a saving of about 20 per cent.

"We think that on an average, 'taking things as they come,' the saving will result about the same as in the other case, namely, 17 per cent."

From another source:

"Four compounds are reported, one of them running two years, one ten months; in all running 117,945 miles in freight service, and 2,946 miles in passenger service. Also, five simple engines, making 1,063,975 engine-miles in freight service, and 3,324 miles in passenger service.

"The chief results are in favor of the compounds, and are as follows:

	Per Cent.
Engine-miles per ton of coal	25·36
Pounds of coal per 100 ton-mile	23·59
" " " " engine-mile	19·00
" " " " car-mile	24·17
" " water per 100 ton-mile	28·85
" " " " engine-mile	16·84
" " " " car-mile	18·91

"We have reports as follows:

	Simple.	*Compound.*
On one road, repairs per train-mile (cents)	2·1	1·5
On another road, repairs per train-mile (cents)	4·11	3·90
" " " " " " " (cents)	3·13	2·88

"These are all the data we have on repairs; and it will be noticed that the compound beats the simple by about 13 per cent.

"The data on lubrication shows that on one road the compound used 12 per cent. more oil than the simple, and on another road 17 per cent. less."

From another source:

"Without giving you the results of any experiments or tests, I should say, in a general way, that a compound loco-

motive, when new, will save about 25 per cent. in fuel over a simple engine.

"I am convinced from our experience here that the compound engine in passenger service is of great value for fast trains, because a run of a hundred miles can be made with one tank of water, thus avoiding any stops, except at division terminals. The use of such engines avoids the necessity for building track tanks, and of course is a great saving. In addition to this, the engines run very much cleaner and make but little smoke when properly handled."

From another source:

"In compliance with my promise to advise you of the performance of your two-cylinder compound engines, I will state that their work is in every respect superb.

"We have had an engine in our express freight service, in competition with two 'Moguls' (simple engines) with 19 x 24-inch cylinders, carrying 160 pounds working steam pressure. These engines are all rated the same, *i. e.*, they are all given trains of 700 tons each. The consumption of coal is as follows: Compound engine ran in April, 1895, 31·1 miles per ton of coal, while the two 'Moguls' averaged 16·2 miles per ton."

From another source:

"These engines are designed to carry 200 pounds steam pressure. They are as nearly alike as possible, although they vary somewhat in their weight.

"The total weight of the compound is 127,500 pounds, and of the simple engine 117,460 pounds. Average steam pressure on test, 150 pounds. Average amount of coal burnt each trip—the compound, 6,150 pounds; the simple, 6,414 pounds. Average coal per car-mile in pounds—the compound, 6·72; the simple, 7·55. Average pounds of water evaporated per pound of coal—compound, 7·86; simple, 6·67. Relative amounts of coal burned on basis of car-mile—the compound, 100 per cent.; the simple, 112·35 per cent.

"The cost of the maintenance of these locomotives in a test occupying so short a time plays no part. The engines, prior to the test, were put in first-class condition, practically as good as new, and the repairs amounted to nothing."

From another source:

"We have in service three two-cylinder compound engines. They have been in service since November, 1894, and we are very well pleased with the general results given by them. They show from 30 to 33 per cent. saving in fuel; about 25 per cent. in evaporation. While there is no claim made for saving in repairs, we find that the cost of repairs is only a fraction of a cent more than the simple engine. The engines are virtually simple engines, having but two cylinders and no complication of parts over simple engines, with the exception of one intercepting valve and one reducing valve.

"Those comparisons were made with simple engines running in the same service and under the same conditions."

From another source:

"We have in service two ten-wheel compound engines of the two-cylinder type and a large number of ten-wheel simple engines, which, with the exception of the compound feature, are duplicates of the two compound engines. These engines have been used in freight service entirely, with the exception of a very small amount of passenger service, and I take pleasure in submitting below a comparative statement of the performance of the engines mentioned during the past five years:"

	Simple.	*Compound.*
Cost per mile for oil and waste (cents)	0·18	0·21
" " " " repairs (cents)	2·49	3·69
Miles run per ton of coal	20·51	22·58
Pounds coal consumed per car-mile	3·10	3·03
Total cost per car per mile (cents)	0·56	0·68

From another source:

"I will give you the figures as returned to me by our Comptroller, of the performance of these engines in regard to fuel.

"In the month of May, 1895, a compound engine, in passenger service, made a mileage of 5,558; her average number of miles per ton of coal was 49·5. Simple engine, in the same service, running opposite to the compound, made a mileage of 4,843, and her average mileage per ton of coal

was 41. These two engines were on night runs, consisting of seven-car trains, postal and baggage cars, two coaches and three sleepers, all vestibule.

"We have had the passenger engine for about eighteen months, and she has given entire satisfaction; is very economical on repairs and especially so on fuel.

"In our freight service we have a two-cylinder compound engine, which, in the month of May, on our fast freight schedule, made 3,003 miles—average miles per ton of coal, 33. Our simple engines running in the same service made a mileage of 2,860—average number of miles per ton of coal, 19·2. Same weight of train.

"The distance from terminal to terminal is 143 miles. The simple engines are limited to 7½ tons of coal per trip, and the compound freight engine was limited to 5 tons of coal per trip.

"I have had no complaint from the engineer running the compound engine of being short of fuel, but I had several complaints from the men running the simple engines where they were short of fuel. The compound engines, both passenger and freight, show a remarkable saving of fuel, and we are highly pleased with their performance."

From another source:

"To say the least, we are very highly pleased with the two-cylinder compound engines. The legitimate cost of repairs is no greater than on the simple engines.

"In the use of cylinder oil they are making about double the mileage of the simple engines, and, on fuel, they are saving at least 25 per cent."

From another source:

"I am pleased to record the fact that we have nineteen of your engines in our service from two to three years, and they have given most excellent satisfaction, both in character of workmanship and effective working and maintenance.

"It is a special pleasure to record the advantages afforded by your type of compound engine, evinced by their economy of fuel and moderate repairs."

THE STANDARD OF EFFICIENCY FOR STEAM-ENGINES AND OTHER HEAT-MOTORS.

BY R. H. THURSTON.

[*Concluded from vol. cxlii, p. 458.*]

The Method of Computation of the efficiency of the cycle for dry and saturated steam is as follows:*

Rankine's Jacketed Engine Cycle.

v_1 = volume in cubic feet at point of cut-off.
= initial volume = volume of 1 pound dry and saturated steam at the pressure chosen.
[Take this from steam-tables.]

v_2 volume at end of expansion.
$= v_1 r$.

r = ratio of expansion.

p_1 = initial pressure in pounds per square foot, absolute.

p_2 = pressure at end of expansion expressed in pounds per square foot, absolute.
[From steam-tables.]

p_3 = back pressure in pounds per square foot, absolute.

J = 778 foot-pounds.

a = 1,117,850 foot-pounds.

b = 544·5 foot-pounds.

T_1 = absolute temperature in degrees F., corresponding to p_1.
[Take temperature from steam-tables, and add 461°.]

T_2 = absolute temperature in degrees F., corresponding to p_2.

* "Manual of the Steam Engine," Vol. I, § 118.

T_4 = absolute temperature in degrees F. of feed-water.

H_1 = heat per pound of steam (at boiler) in foot-pounds.
$= J(\lambda_1 - q_4)$.

H' = heat expended per pound of working steam, in foot-pounds.
= H_1 plus the heat received by the working steam from the jacket.

$$= J(T_2 - T_4) + a\left(1 + \log_e \frac{T_1}{T_2}\right) - b\,T_1.$$

Enter this in place of H_1 in the table.
"Working steam" is the steam passed through the cylinder.

U = net work done, in foot-pounds, per pound of working steam.

$$= a \log_e \frac{T_1}{T_2} - b(T_1 - T_2) + v_2(p_2 - p_3).$$

$$\text{Efficiency} = \frac{U}{H'_1}.$$

$$\text{M.E.P.}' = \frac{U}{r\ v_1} = \frac{U}{v_2} \text{ in pounds per square foot.}$$

$$\text{M.E.P.}'' = \frac{\text{M.E.P.}'}{144} \text{ in pounds per square inch.}$$

A = B.T.U. per I.H.P. per hour $= \dfrac{2545}{\text{Efficiency}}$.

B = pounds of steam per I.H.P. per hour at boiler (inclusive of jacket-steam) for efficiency unity.

$$= \frac{1980000}{H_1} = \frac{1980000}{J(\lambda - q_4)}.$$

B' = pounds of working steam per I.H.P. per hour for efficiency unit.

$$= \frac{1980000}{H'_1}.$$

C = pounds of steam per I.H.P. per hour, total (jacket and working charge) for actual efficiency.

$$= \frac{B}{\text{Efficiency}}.$$

C' = pounds of working steam per I.H.P. per hour for actual efficiency.

$$= \frac{B'}{\text{Efficiency}}.$$

W = equivalent water-rate from and at 212° F.

$$= \frac{A}{966069}.$$

F = pounds fuel per I.H.P. per hour.

$$= \frac{A}{10000}.$$

D = piston displacement per I.H.P. per hour.

$= C' v_2$ cubic feet.

D' = piston displacement per I.H.P. per minute.

$$= \frac{D}{60}.$$

Illustrative Examples follow, in which the maximum steam-pressure is assumed to be exceptionally high, 400 to 500 pounds per square inch, absolute, the terminal pressures to be identical with the back-pressures in the case of the Carnot cycle, and to be usually 7 pounds per square inch in the condensing and 21 pounds in the non-condensing engine; while the back-pressures are taken at 2 and at 16 pounds, respectively, for the condensing and the non-condensing engines and for their Carnot representatives.

The methods which have been outlined are followed in these cases, and the results of computation by various computers give an excellent series of data for comparison, bringing out well the relative efficiencies of the several cycles as well as their absolute efficiencies, and serving also to exhibit, in an instructive manner, when compared with the real engine cycle, the extent and the character of the physical defects of the actual engine.

In these cases, it is assumed that the quality of the fuel and the efficiency of the boiler are such as to permit the evaporation of 10 pounds of the feed-water supplied, per

pound of fuel, in the case of the non-condensing engine—which is supposed to employ a heater capable of raising the temperature of the feed-water to 200° F.—of 9 pounds in the case of the condensing engine, taking the feed-water from its hot-well, and 12 pounds in the Carnot engine, the "feed-water" being, in this case, at the temperature of the prime steam, and only demanding its heat of vaporization to transform it into steam of boiler-pressure.

CASE I. THE CARNOT CYCLE.

(*a*) In this case the data and results are as follows:

(*a*) "*Non-condensing*" *Type.*

$p_1 = 400 \times 144 = 57{,}600$ pounds per square foot.
$V_1 = 1{\cdot}167$ cubic feet.
$T_1 = 905{\cdot}92°$ F., absolute.

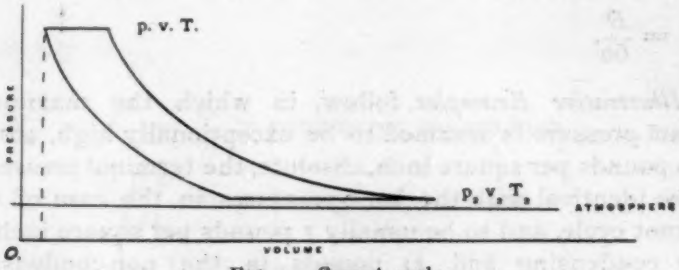

FIG. 3.—Carnot cycle.

$p_2 = 16 \times 144 = 2{,}304$ pounds per square foot.

$V_2 =$ or from $V_1 \left(\frac{p}{p}\right)^{\cdot 881} = 20{\cdot}83$ cubic feet.

$T_2 = 677{\cdot}347°$ F., absolute.

$log.\, p_1 = 4{\cdot}760422$ $\quad log.\left(\frac{p_1}{p_2}\right)^{\cdot 881} = 1{\cdot}251585.$

$log.\, p_2 = 3{\cdot}362482$ $\quad log.\, v_1 = {\cdot}067071.$

$log.\, \frac{p_1}{p_2} = 1{\cdot}397940$ $\quad log.\, V_2 = 1{\cdot}318656$ $\quad V_2 = 20{\cdot}83.$

$L_1 = 797{\cdot}94$ B.T.U.

$H_1 =$ heat expended per pound of steam in foot-pounds.
$= J\, L_1 = 797{\cdot}95 \times 778 = 620797.$

r, ratio of expansion $= \frac{v_2}{v_1} = \frac{20{\cdot}83}{1{\cdot}167} = 17{\cdot}85$.

$J = 778$ feet per heat unit.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1} = \frac{905{\cdot}92 - 677{\cdot}347}{905{\cdot}92} = 25{\cdot}3 \text{ per cent.}$$

U = net work per pound of steam expresssed in foot-pounds.

$= H_1 \times \text{Efficiency} = 620797 \times 0{\cdot}253 = 157{,}062$ foot-pounds.

$\text{M.E.P.}' = \frac{u}{v_2}$ in pounds per square foot $= 7{,}540$.

$$\text{M.E.P.}'' = \frac{\text{M.E.P.}'}{144} = 52{\cdot}4 \text{ pounds per square inch.}$$

A = B.T.U. per horse-power per hour $\frac{\frac{33000 \times 60}{778}}{\text{Efficiency}} = \frac{2545}{\text{Efficiency}}$.

$$= \frac{2545}{0{\cdot}253} = 10059.$$

This value of A is, however, for an efficiency of boiler of unity; but, according to the assumptions of the problem, the boiler efficiency was such as to evaporate 12 pounds of water per pound of coal of 10,000 B.T.U. If the efficiency were unity, the number of pounds evaporated would be:

$$\frac{10000}{797{\cdot}94} = 13{\cdot}79 \text{ pounds.}$$

Then A_1 = B.T.U. supplied to boiler will equal $\frac{A}{\text{Efficiency of boiler}}$. Efficiency of boiler $= \frac{12}{13{\cdot}79} = 87{\cdot}01$ per cent.

$$A_1 = \frac{A}{{\cdot}8781} = \frac{10059}{{\cdot}8701} = 11558 \text{ B.T.U. per horse-power.}$$

B = pounds of steam per horse-power per hour for efficiency unity $= \frac{1980000}{H_1} = \frac{1980000}{620797} = 3{\cdot}19$ pounds.

C = pounds of steam per horse-power per hour for actual efficiency $= \frac{B}{\cdot 253} = 12\cdot 6$ pounds.

W = equivalent water-rate from and at 212° F. $= \frac{A}{966\cdot 069} = \frac{10059}{966\cdot 069} = 10\cdot 41$ pounds.

T = pounds of fuel per horse-power for efficiency unity $= \frac{A}{10000} = \frac{10059}{10000} = 1\cdot 0059$ pounds.

F_1 = pounds of fuel per horse-power per hour for efficiency of boiler of 87·01 per cent. $= \frac{F}{\cdot 8701} = \frac{1\cdot 0059}{\cdot 8701} = 1\cdot 15$ pounds.

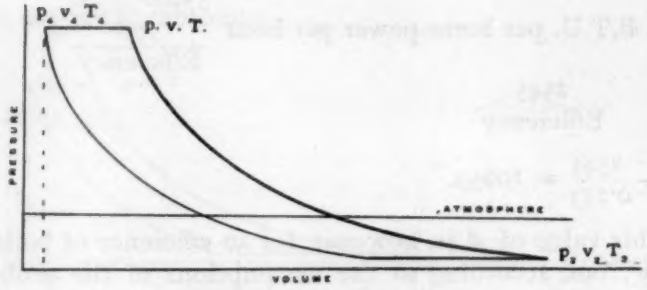

FIG. 4.—Carnot cycle.

D = piston displacement per horse-power per hour = $C v_2$ cubic feet = 12·6 × 20·83 = 262·46.

D_1 = piston displacement per horse-power per minute = $\frac{D}{60} = \frac{262\cdot 46}{60} = 4\cdot 347$ cubic feet.

(*b*) "*Condensing*" *Type.*

p_1 = 400 × 144 = 57,600 pounds per square foot.
V_1 = 1·167 cubic feet.
T_1 = 905·92° F., absolute.
p_2 = 2 × 144 = 288 pounds per square foot.
$V_2 = V\left(\frac{p_1}{p_2}\right)^{\cdot 881} = 106\cdot 45$.
T_2 = 587·302° F., absolute.

$L_1 = 797{\cdot}94$ B.T.U.

r = ratio of expansion $= \frac{v_2}{v_1} = \frac{106{\cdot}45}{1{\cdot}167} = 91{\cdot}23$.

$J = 778$ foot-pounds per heat unit.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1} = \frac{905{\cdot}92 - 587{\cdot}302}{905{\cdot}92} = 35{\cdot}17 \text{ per cent.}$$

$H_1 = J L_1 = 620797$.

$U = H_1 \times \text{Efficiency} = 620797 \times {\cdot}3517 = 218332$.

$\text{M.E.P.}' = \frac{u}{v_2}$ in pounds per square foot $= 2050{\cdot}1$.

$\text{M.E.P.}'' = \frac{\text{M.E.P.}'}{144} = 14{\cdot}2$ pounds per square inch.

A = B.T.U. per horse-power per hour $= \frac{2545}{\text{Efficiency}}$

$= \frac{2545}{{\cdot}3517} = m\,7236$ B.T.U.

$A_1 = \frac{A}{\text{Efficiency of boiler}}$. Efficiency of boiler $= 87{\cdot}01$

$= \frac{7236}{{\cdot}8701} = 8317$.

$B = \frac{1980000}{H_1} = \frac{1980000}{620797} = 3{\cdot}19$.

$C = \frac{B}{\text{Efficiency}} = \frac{B}{{\cdot}3517} = \frac{3{\cdot}19}{{\cdot}3517} = 9{\cdot}07$.

$W = \frac{A}{966{\cdot}069} = 7{\cdot}49$ pounds.

$F = \frac{A}{10000}$ = pounds fuel per horse-power per hour for efficiency unity of boiler, and taking 10000 as the B.T.U. in pounds coal—

$= \frac{7236}{1000} = {\cdot}7236$ pounds.

F_1 = pounds coal for actual efficiency of boiler.

$= \frac{F}{{\cdot}87} = {\cdot}837$ pounds coal per horse-power per hour.

D = piston displacement per horse-power per hour.
$= c\, v_2$ cubic feet $= 9{\cdot}07 \times 106{\cdot}45 = 976{\cdot}15$.

D_1 = piston displacement per horse-power per minute.

$$= \frac{D}{60} = 16{\cdot}27 \text{ cubic feet.}$$

CASE II. RANKINE CYCLE. NON-CONDUCTING CYLINDER.

(*a*) *Condensing Type.*

$p_1 = 400 \times 144 = 57600$ pounds per square foot.
$V_1 = 1{\cdot}167$ cubic feet.
$T_1 = 905{\cdot}92°$ F., absolute.
$p_2 = 7 \times 144 = 1008$ pounds per square foot.
$T_2 = 639{\cdot}945°$ F., absolute.

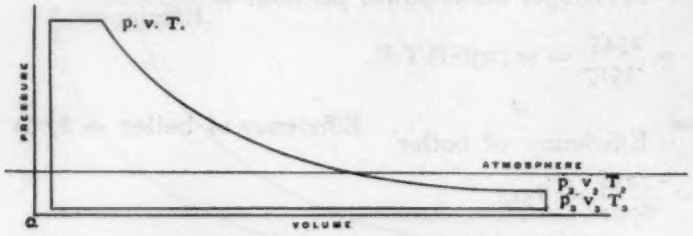

FIG. 5.—Rankine cycle. Non-conducting cylinder.

$$V_2 = v_1 \left(\frac{p_1}{p_2}\right)^{\frac{1}{1{\cdot}135}} = v_1 \left(\frac{p_1}{p_2}\right)^{{\cdot}881} = 41{\cdot}205.$$

$$r = \frac{v_1}{v_2} = \left(\frac{p_1}{p_2}\right)^{{\cdot}881} = 35{\cdot}3.$$

$p_3 = 2 \times 144 = 288$ pounds per square foot.
$J = 778$ foot-pounds per heat unit.
$log.\ p_1 = 4{\cdot}760422.$

$$log.\ p_2 = \frac{3{\cdot}003461}{1{\cdot}756961}.$$

$$log. \left(\frac{p_1}{p_2}\right)^{{\cdot}881} = 1{\cdot}547883.$$

$log.\ v_1 = {\cdot}067071.$
$log.\ v_2 = 1{\cdot}614954.$
$T_3 = 587{\cdot}302°$ F., absolute.

T_4 = 120 + 461 = 581° F., absolute.

λ_1 = total heat of evaporation above 32° in B.T.U. at p = 1217·7.

q_4 = heat in feed-water above 32° at T_4 in B.T.U.
= 581° − (461 + 32) = 581 − 493 = 88 B.T.U.

U = net work of a pound of steam in foot-pounds for efficiency of engine.

$$= J_1 \left[T_1 - T_2 \left(1 + \log_e \frac{T_1}{T_2} \right) \right] + \left(\frac{T_1 - T_2}{T_1} \right) H' + v_2 (p_2 - p_3)$$

$$= 778\,[905{\cdot}92 - 639{\cdot}945\,(1{\cdot}3365)] + \frac{265{\cdot}975}{905{\cdot}92} H' +$$

$$41{\cdot}205 \times 720 = 250470 \text{ foot-pounds.}$$

L_1 = latent heat evaporation at p in B.T.U. = 797·94.

H' = latent heat evaporation at p in foot-pounds = $J L_1$ = 620997.

H_1 = heat expended per pound of steam in foot-pounds.
$= J (\lambda - q_4) = 778\,(1217{\cdot}7 - 88) = 878806{\cdot}6.$

$$\text{Efficiency} = \frac{u}{H_1} = \frac{250470}{878806} = 28{\cdot}5 \text{ per cent.}$$

$$\text{M.E.P.}' = \frac{u}{r\ v_1} = \frac{u}{v_2} = \text{in pounds per square foot} = 6979.$$

$$\text{M.E.P.}'' = \frac{\text{M.E.P.}'}{144} = 42{\cdot}215 \text{ pounds per square inch.}$$

B = pounds steam per horse-power per hour for efficiency unity $= \dfrac{1980000}{H_1} = 2{\cdot}36$ pounds.

A = B.T.U. per horse-power per hour.

$$= \frac{2545}{\text{Efficiency}} = \frac{2545}{{\cdot}285} = 8930.$$

C = pounds of steam per horse-power per hour for actual efficiency $= \dfrac{B}{\text{Efficiency}} = \dfrac{2{\cdot}36}{{\cdot}285} = 8{\cdot}28.$

W = equivalent water-rate from and at 212° F.

$$= \frac{A}{966{\cdot}069} = 9{\cdot}24 \text{ pounds.}$$

F = fuel per horse-power per hour for boiler efficiency unity

$$= \frac{A}{10000} = \cdot 8930.$$

F' = actual fuel per horse-power per hour for evaporation, 9 pounds water per pound coal.

$$= \frac{C}{9} = \frac{8 \cdot 28}{9} = \cdot 92 \text{ pounds coal per horse-power per hour.}$$

D = piston displacement per horse-power per hour.

$= C\,V_2$ cubic feet $= 8 \cdot 28 \times 41 \cdot 205 = 241 \cdot 18$ cubic feet.

D' = piston displacement per horse-power per minute.

$$= \frac{D'}{60} = \frac{341 \cdot 18}{60} = 5 \cdot 68 \text{ cubic feet per minute.}$$

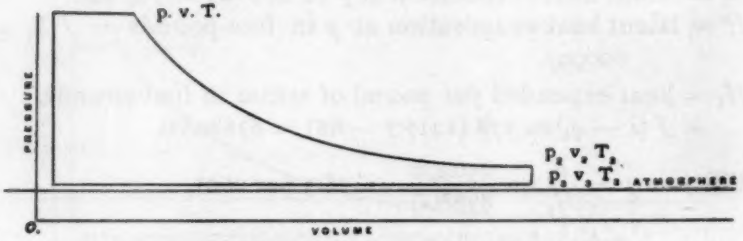

FIG. 6.—Rankine cycle. Non-conducting cylinder.

(*b*) *Non-condensing Type.*

$p_1 = 400 \times 144 = 57600$ pounds per square foot.

$T_1 = 905 \cdot 92°$ F., absolute.

$V_1 = 1 \cdot 167$.

$p_2 = 21 \times 144 = 3024$ pounds per square foot.

$$V_2 = V_1 \left(\frac{p_1}{p_2}\right)^{\cdot 881}$$

$log.\, p_1 = 4 \cdot 760422$ $\quad log. \left(\frac{p_1}{p_2}\right)^{\cdot 881} = 1 \cdot 138539$

$log.\, p_2 = 3 \cdot 480582$ $\quad log.\, v_1 = \cdot 067071$

$log. \frac{p_1}{p_2} = 1 \cdot 279840$ $\quad log.\, v_2 = 1 \cdot 205610$

$V_2 = 16 \cdot 06$.

$T_2 = 230 \cdot 565 - 461 = 691 \cdot 565°$ F., absolute.

$$r = \frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{\cdot 881} = 13 \cdot 7.$$

J = 778 foot-pounds per heat-unit.

T_3 = temperature F. degrees, absolute, of $p_3 = 677{\cdot}347$.

T_4 = absolute temperature F. feed-water = 461 + 200 = 661°.

λ_1 = total heat of evaporation at $p_1 = 6771217{\cdot}7$ B.T.U.

q_4 = heat in feed-water per pound above 32° in B.T.U.
$= T_4 - (461 + 32) = 661 - 493 = 168$.

$p_3 = 144 \times 16 = 2304$.

L_1 = latent heat of evaporation at p_1 in B.T.U. = 797·94.

H' = latent heat of evaporation at p in foot-pounds $= J L_1$
$= 62797$.

U = net work of a pound of steam in foot-pounds for the efficiency of the engine.

$$= J\left[T_1 - T_2\left(1 + log._e \frac{T_1}{T_2}\right)\right] + \left(\frac{T_1 - T_2}{T_1}\right)H' - V_2 (p_2 - P_3).$$

$$\frac{T_1}{T_2} = \frac{905{\cdot}92}{691{\cdot}565} = 1{\cdot}31 \qquad log._e \frac{T_1}{T_2} = {\cdot}27.$$

$$\frac{T_1 - T_2}{T_1} = \frac{214{\cdot}36}{905{\cdot}92} = {\cdot}2366.$$

$$U = 778\,[905{\cdot}92 - 691{\cdot}565\,(1{\cdot}27)] + ({\cdot}2366 \times 620797) - 16{\cdot}06 \times 720.$$
$$= 21493{\cdot}92 + 146880{\cdot}5 + 11563{\cdot}2.$$
$$= 169937{\cdot}6.$$

H_1 = heat expended per pound of steam, in foot-pounds.
$= J(\lambda_1 - q_4) = 778\,(1217{\cdot}7 - 168) = 816666{\cdot}6$ foot-pounds.

$$\text{Efficiency} = \frac{U}{H_1} = \frac{169937{\cdot}6}{816666{\cdot}6} = 20{\cdot}82 \text{ per cent.}$$

$$\text{M.E.P.}' = \frac{U}{r\,v_1} = \frac{U}{v_2} \text{ pound per square foot} = \frac{169937{\cdot}6}{1606}$$
$$= 10581.$$

M.E.P.″ = mean effective pressure in pounds per square inch $= \dfrac{\text{M.E.P.}'}{144} = 73{\cdot}48$.

A = B.T.U. per horse-power per hour.

$$= \frac{2545}{\text{Efficiency}} = \frac{2545}{{\cdot}2082} = 12235.$$

B = pounds steam per horse-power per hour for efficiency unity $= \frac{1980000}{H_1} = \frac{1980000}{816666{\cdot}6} = 2{\cdot}42$ pounds.

C = pounds steam per horse-power per hour actual efficiency engine $= \frac{B}{\text{Efficiency}} = \frac{2{\cdot}42}{{\cdot}2082} = 11{\cdot}68$ pounds.

F' = pounds coal actual per horse-power per hour for efficiency of boiler such as to evaporate 10 pounds water from temperature 200° to steam at 400 pounds per square inch.

$= \frac{C}{10} = \frac{11{\cdot}68}{10} = 1{\cdot}168$ pounds coal.

W = equivalent water-rate from and at 212° F.

$= \frac{A}{966{\cdot}069} = \frac{12235}{966{\cdot}069} = 13{\cdot}66.$

D = piston displacement per horse-power per hour.
$= C\,V$ cubic feet — $11{\cdot}68 \times 16{\cdot}06 = 187{\cdot}58$ cubic feet.

D' = piston displacement per horse-power per minute.

$= \frac{D}{60} = \frac{187{\cdot}58}{60} = 3{\cdot}126$ cubic feet.

CASE II. RANKINE'S JACKETED CYCLE.

(*a*) *Condensing Type.*

$p_1 = 400 \times 144 = 57600$ pounds per square foot, absolute.
$V_1 = 1{\cdot}167$ cubic feet volume at cut-off of 1 pound at p_1.
$T_1 = 905{\cdot}92° =$ F. absolute temperature at cut-off.
$p_2 = 7 \times 144 = 1008$ pounds per square foot, absolute.
$T_2 = 639{\cdot}945°$ F., absolute, of steam at p_2.
$v_2 = 52{\cdot}89$ cubic feet volume of saturated steam at pressure p_2.
$p_3 = 2 \times 144 = 288$ pounds per square foot, absolute = back pressure.
$T_4 = 120 + 461 = 581°$ absolute F. temperature of feed-water.
$J = 778$ foot-pounds per heat unit.
$a = 1{\cdot}117850$ foot-pounds, a constant.

b = 544·5 foot-pounds, a constant.

H_1 = heat per pound of steam at boiler in foot-pounds.
= $J(\lambda_1 - q_4)$ = 878806·6 foot-pounds.

λ_1 = total heat of evaporation above 32° per pound steam at p.
= 1217·7 B.T.U.

q_4 = heat in feed-water above 32° F.
= $T_4 - (493)$ = 581 − 493 = 88 B.T.U.

H_1' = heat expended per pound working steam in foot-pounds.
= H_1 plus heat received from the jacket.

$$= J(T_2 - T_4) + a\left(1 - log_e \frac{T_1}{T_2}\right) - b\,T_1.$$

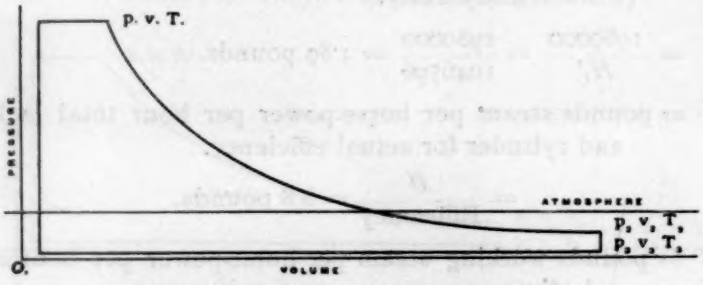

FIG. 7.—Rankine cycle. Jacketed cylinder.

$= J(T_2 - T_4) + a(1{\cdot}3365) - b\,T_1.$
$= 778\,(58{\cdot}945) + 1{\cdot}117850 \times 1{\cdot}3365 - 544{\cdot}5 \times 905{\cdot}92.$
$= 45863{\cdot}1 + 1494006{\cdot}5 - 493273{\cdot}4.$
= 1046596 foot-pounds.

U = net work done in foot-pounds per pound "working steam."

$$= a\,log_e \frac{T_1}{T_2} - b\,(T_1 - T_2) + v_2\,(p_2 - p_3).$$

$= 1117850 \times {\cdot}3365 - 544{\cdot}5 \times 265{\cdot}965 + 52{\cdot}89 \times 720.$
$= 376156{\cdot}5 - 146817{\cdot}2 + 38080{\cdot}8.$
= 267420·1 foot-pounds.

$$\text{Efficiency} = \frac{U}{H_1'} = \frac{267420{\cdot}1}{1046596{\cdot}2} = 25{\cdot}55 \text{ per cent.}$$

M.E.P.$' = \frac{U}{r\, v_1} = \frac{U}{v_2}$ in pounds per square foot = 5056·16.

M.E.P.$'' = \frac{\text{M.E.P}'}{144}$ in pounds per square inch = 35·11 pounds.

B = pounds of steam per horse-power per hour at boiler, inclusive of jacket-steam, for efficiency unity.

$$= \frac{1980000}{H_1} = \frac{1980000}{878806{\cdot}6} = 2{\cdot}25 \text{ pounds.}$$

A = B.T.U. per horse-power per hour $= \frac{2545}{\text{Efficiency}} = 9960{\cdot}9.$

B' = pounds of working steam per horse-power per hour for efficiency unity.

$$= \frac{1980000}{H_1'} = \frac{1980000}{1046596} = 1{\cdot}89 \text{ pounds.}$$

C = pounds steam per horse-power per hour total jacket and cylinder for actual efficiency.

$$= \frac{B}{\text{Efficiency}} = 8{\cdot}8 \text{ pounds.}$$

C' = pounds working steam per horse-power per hour actual efficiency.

$$= \frac{B'}{\text{Efficiency}} = \frac{1{\cdot}39}{{\cdot}2555} = 7{\cdot}4 \text{ pounds.}$$

W = equivalent water-rate from and at 212° F.

$$= \frac{A}{966{\cdot}069} = 10{\cdot}3.$$

F = fuel per horse-power per hour

$$= \frac{A}{\text{B.T.U.}} \text{ per pound coal} = 10000.$$

= also, pounds steam per horse-power for actual efficiency of engine, divided by pounds coal per pound steam, in this case assumed at 9 pounds,

$$\frac{99609}{10000} = {\cdot}996 \text{ pound.}$$

$F' = \frac{C}{9} = \frac{8{\cdot}8}{9} = {\cdot}978$ pound.

D = piston displacement per horse-power per hour.
$= C\,v_2$ cubic feet $= 8{\cdot}8 \times 52{\cdot}89 = 465{\cdot}4$.

$D' = \frac{D}{144} = 3{\cdot}25$ cubic feet displacement per horse-power per minute.

r = ratio of expansion.
$= \frac{v_2}{v_1} = \frac{52{\cdot}89}{1{\cdot}167} = 45{\cdot}3$.

(*b*) *Non-Condensing Type.*

p_1 $= 400 \times 144 = 57600$ pounds per square foot, absolute.
v_1 $= 1{\cdot}167$ cubic feet volume at cut-off at pressure p_1.

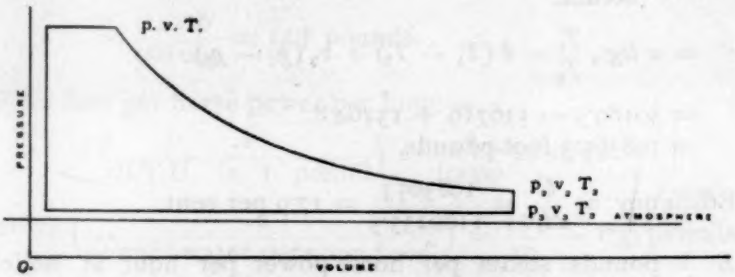

FIG. 8.—Rankine cycle. Jacketed cylinder.

T_1 $= 905{\cdot}92°$ F. absolute temperature at cut-off.
p_2 $= 21 \times 144 = 2304$ pounds per square foot, absolute.
v_2 $= 18{\cdot}84$ cubic feet volume at pressure p_2 of a pound of saturated steam.
T_2 $= 691{\cdot}565°$ absolute F. temperature saturated steam at $p_2\,v_2$.
p_3 $= 16 \times 144 = 2304$ pounds per square foot, absolute.
$=$ back pressure.
T_4 $= 200 + 461 = 661°$ F. absolute temperature feed-water.
J $= 778$ foot-pounds per heat unit.
a $= 1117850$ foot-pounds, a constant.
b $= 544{\cdot}5$ foot-pounds, a constant.
λ_1 $=$ total heat of evaporation per pound steam above 32°.
$= 1217{\cdot}7$ B.T.U.

q_4 = heat in feed-water above 32° F.
$= T_4 - (4 - 3) = 661 - 493 =$ B.T.U. $= 168$.

r = ratio of expansion.

$$= \frac{v_2}{v_1} = \frac{18{\cdot}84}{1{\cdot}167} = 16{\cdot}14.$$

H_1 = heat per pound steam at boiler in foot-pounds.
= H_1 + heat received from the jacket.

$$= J(T_2 - T_4) + a\left(1 + log._e \frac{T_1}{T_2}\right) - b\,T_1.$$

$$= 778\,(300{\cdot}565) + (1117850 \times 1{\cdot}27) - (544{\cdot}5 \times 905{\cdot}92).$$
$$= 233839{\cdot}5 + 1419669{\cdot}5 - 493273{\cdot}4.$$
$$= 1160235{\cdot}5.$$

U = net work done in foot-pounds per pound "working steam."

$$= a\ log._e \frac{T_1}{T_2} - b\,(T_1 - T_2) + v_2\,(p_2 - p_3).$$

$$= 30189{\cdot}5 - 116719 + 13264{\cdot}8.$$
$$= 198365{\cdot}3 \text{ foot-pounds.}$$

$$\text{Efficiency} = \frac{U}{H_1'} = \frac{1983653}{1160235{\cdot}5} = 17{\cdot}9 \text{ per cent.}$$

B = pounds steam per horse-power per hour at boiler, inclusive of jacket-steam, for efficiency unity.

$$= \frac{1980000}{H_1} = \frac{1980000}{816666{\cdot}6} = 2{\cdot}42 \text{ pounds.}$$

B' = pounds of working steam per horse-power per hour for efficiency unity.

$$= \frac{1980000}{H_1'} = \frac{1980000}{1{\cdot}1602355} = 1{\cdot}707.$$

A = B.T.U. per horse-power per hour for actual efficiency.

$$= \frac{2525}{\text{Efficiency}} = \frac{2525}{{\cdot}179} = 14220.$$

$$\text{M.E.P.}' = \frac{U}{r\,v_1} = \frac{U}{v_2} = \frac{198365{\cdot}3}{18{\cdot}84} = 10529 \text{ pounds per square foot.}$$

$$\text{M.E.P.}'' = \frac{\text{M.E.P.}'}{144} = 73{\cdot}1 \text{ pounds per square inch.}$$

C = pounds steam per horse-power, total for both jacket and cylinder, for actual efficiency.

$$= \frac{B}{\text{Efficiency}} = \frac{2{\cdot}42}{{\cdot}179} = 13{\cdot}5 \text{ pounds.}$$

C' = pounds "working steam" per horse-power per hour, actual efficiency.

$$= \frac{B'}{\text{Efficiency}} = \frac{1{\cdot}707}{{\cdot}179} = 9{\cdot}5 \text{ pounds.}$$

W = equivalent water-rate from and at 212° F. $= \dfrac{A}{966{\cdot}069}$

$$= \frac{14220}{966{\cdot}069} = 14{\cdot}7 \text{ pounds.}$$

F = fuel per horse-power per hour =

$$\left(\frac{A}{\text{B.T.U. in 1 pound}}\right) = \frac{A}{10000} = 14{\cdot}22.$$

$$F' = \left(\frac{C}{\text{pounds water per pound coal}}\right) = \frac{13{\cdot}5}{10} = 1{\cdot}35 \text{ pounds.}$$

D = piston displacement per horse-power per hour $= C v_2$ $= 254{\cdot}34$ cubic feet.

D' = piston displacement per horse-power per minute $= \dfrac{D}{60} = 4{\cdot}24$ cubic feet.

SUMMARY.

IDEAL STEAM-ENGINE CYCLES; $p_1 = 400$ POUNDS PER SQUARE INCH.

	Carnot Cycle.		Rankine Non-Conducting Cycle.		Rankine Jacketed Cycle.	
	Condensing.	Non-Condensing.	Condensing.	Non-Condensing.	Condensing.	Non-Condensing.
r	91·23	17·85	35·3	13·7	45·3	16·14
v_2	106·45	20 83	41·2	16·06	52·89	18·84
p_2	288	2,304	1,008	3,024	1,008	3,024
T_2	587·3	677·347	639·9	691·56	639·94	691·56
H_1	620,797	620,797	898,806	816,666	878,806	816,666
U	218,332	157,062	250,470	169.937	267,420	198,365
Efficiency, per cent. (computed)	35·17	25·3	28·5	20·82	25·55	17·9
M.E.P.′, pounds per square foot	2,050	7,540	6.079	10,581	5,056	10,529
M.E.P.″, pounds per square inch	14·2	52·4	42·2	73·48	35·11	73·1
A, B.T.U. per horse-power per hour	7,236	10,059	8,930	12,235	9960·9	14,220
B, pounds steam per horse-power per hour for efficiency = 1	3·19	3·19	2·36	2·42	2·25	2 42
C, pounds steam for computed efficiency	9·07	12·6	8·28	11 68	8·8	13·5
W, "water-rate" from and at 212° F.	7·49	10·41	9·24	13·66	10·3	14·7
F, pounds fuel for computed efficiency	·83	1·15	·92	1·168	·978	1·35
D, piston displacement per I.H.P. per hour	976·1	262·46	341·1	187·58	465·4	254·3
D', piston displacement per I.H.P. per minute	16·27	4·374	5 68	3·126	3·25	4·24
p_1, pounds per square foot	57,600	57,600	57,600	57,600	57,600	57,600
p_2, pounds per square foot	288	2·304	288	2,304	288	2,304
T_1 (absolute)	905·92	905·92	905·92	905·92	905·92	905·92
T_2 "	587·3	677·347	587·3	677·347	587·3	677·34
T_4 "	905·92	905·92	581·	661·	581·	661·

The Ranges of the Efficiencies computed as obtainable in these ideal cases—which efficiencies are especially important and interesting as constituting the limits toward which the engineer seeks to approximate, while knowing that it is impossible to pass them and impracticable to secure even a very close correspondence in the operation of his real engines—may be noted in the succeeding tables. The pressures

adopted for prime steam are from 150 pounds to 500; *i. e.*, from what is now coming to be a familiar pressure up to a tension which very possibly may prove to be beyond that of profitable utilization in the real engine for a long time to come. The terminal pressures are those due the ratios of expansion specified, and the back-pressures are as low, and, therefore, the efficiencies as high, as modern practice justifies us in expecting for the ideal cases representative of the most successful practice. These figures may be profitably compared with those computed by Rankine, at the middle of the nineteenth century, as corresponding to the cycle of the steam-engine of that date.* The economical gain by the reduction of the back-pressure to the figures now attainable, with such good design and construction as has been readily secured in recent years, is seen to be very considerable. Ample port-area and a tight condenser are obviously elements of economy which it is well worth while to insure.

CARNOT CYCLE.

IDEAL CASE; $p_2 = p_3 = 2$; CORRESPONDING TO $T_2 = 587°$.

Case I.

p_1	150	200	250	300	350	400	450	500
T_1	819·2	841·6	861·9	878·36	892·9	905·92	917·6	928·4
r	44·8	57·8	70·4	82·63	94·6	106·5	118	129·6
V_2	133	130·4	128·4	126·83	125·4	124·2	123·3	122
H_1	671,000	656,000	646,097	636,604	628,219	620,797	613,000	607,618
U	190,000	198,500	205,000	210,079	218,900	218,500	221,000	222,000
E	28·3	30·3	31·9	33·1	34·2	35·1	36·	36·7
M.E.P.′ . . .	1,427	1,522	1,604·9	1,695	1,712·1	1,758·2	1,800	1,820
M.E.P.″ .	10·01	10·56	11·13	11·55	11·85	12·2	12·5	12·7
A	9,000	8,430	7,986	7,730	7,450	7,236	7,050	6,934
B	2·93	3·02	3·08	3·11	3·15	3·19	3·23	3·26
C	10·45	9·98	9·69	9·4	9·2	9·0	8·94	8·89
W	9·32	8·73	8·27	7·93	7·73	7·49	7·32	7·19
F	·90	·832	·799	·773	·745	·724	·705	·698
D	1,390	1,300	1,236	1,190	1,157	1,115	1,100	1,090
D'	22·8	21·7	20·6	19·9	19·28	18·58	18·3	18·1

* Thurston's "Manual of the Steam-Engine," Vol. I, § 117.

CARNOT CYCLE.

IDEAL CASE; $p'_2 = p'_3 = 16$; NON-CONDENSING; $T'_2 = 677°35$.

Case II.

p_1	150	200	250	300	350	400	450	500
T_1	819·22	842·63	861·88	878·376	892·96	905·92	917·62	927·2
r	7·18	9·25	11·3	13·23	15·1	17·05	18·8	21·02
V_2	21·27	20·87	20·56	20·3	20·07	19·89	19·627	19·51
H_1	670,324	657,080	646,097	636,641	628,150	620,797	613,935	607,618
U	115,966	128,880	138,264	145,727	151,800	157,062	160,728	164,061
E	17·3	19·69	21·4	22·9	24·2	25·3	26·5	27·1
M.E.P.′ . . .	5,450	6,175	6,730	7,178	7,570	7,865	8,159	8,360
M.E.P.″ . .	38	42·8	46·6	49·09	54·2	54·6	56·6	57·0
A	14,710	12,990	11,886·9	11,123	10,530	10,059	9721·16	94·25
B	2·95	3·02	3·06	3·2	3·16	3·19	3·24	3·26
C	17·05	15·35	14·3	13·6	13·08	12·6	12·22	12·07
W	15·3	13·43	12·3	11·5	10·9	10·4	10·06	9·47
F	1·48	1·298	1·19	1·112	1·053	1·01	·972	·941
D	353	321	294	278·2	262·5	262·4	240	237·5
D'	5·89	5·35	4·91	4·63	4·37	4·34	4·03	3·92

RANKINE'S NON-CONDUCTING CYCLE.

IDEAL CASE; $p_2 = p_3 = 2$; CONDENSING; $T_2 = 587°$.

Case III.

p_1	150	200	250	300	350	400	450	500
T_1	819·22	842·63	861·88	878·369	892·96	905·9	917·62	927·2
r	14·87	19·34	25·	27·4	31·4	35·4	39·17	43·02
V_2	44·04	43·25	42·6	42·06	41·55	41.25	40·82	40·5
H_1	858,289	863,813	868,411	872.323	875,827	878,890	881,707	885,000
U	197,624	212,305	223,805	233,120	232,231	242,042	256,526	262,050
E	23	24·5	25·87	26·7	26·5	27·3	29·09	29·6
M.E.P.′ . . .	4,521	4,908	5188·7	5,260	5,583	5,875	6,170	6,375
M.E.P.″ . .	31·16	34·2	35·5	36·6	38·77	40·75	42·64	45·5
A	11,065	10,386	9,910	9,875	9,603	9,254	8,748	8,600
B	2·3	2·29	2·28	2·27	2·26	2·25	2·25	2·24
C	10·	9·35	8·88	8·52	8·54	8·36	7·7	7·57
W	11·4	10·7	10·3	10·2	9·9	9·2	9·0	8·9
F	1·107	1·03	·991	·987	·96	·925	·875	·843
D	440·4	397·	387·1	376·2	355·	328·	316·	306·3
D'	7·3	6·7	6·4	6·2	5·9	5·6	5·3	5·1

RANKINE'S NON-CONDUCTING CYCLE.

IDEAL CASE; $p_2' = p_3' = 16$; NON-CONDENSING; $T_2' = 677°35$.

Case IV.

p_1	150	200	250	300	350	400	450	500
T_1	819°2	842°63	861°88	878°37	892°96	905°9	917°62	928°4
r	5°64	7°28	8°91	10°44	11°9	13°4	14°88	16°3
V_2	16°7	16°4	16°2	16°03	15°79	15°69	15°45	15 35
H_1	796,049	803,500	805,000	809,898	813,585	816,000	821,000	822,500
U	126,555	142.720	151383°76	164.457	169,959	177,380	186,152	192,820
E	15°9	17°3	18°92	19°9	20°8	21°9	22°7	23°4
M.E.P.′ . .	7,754	8,460	9,219	10,200	10,763	10.940	11,310	12,540
M.E.P.″ . .	52°2	58°8	64°02	70°5	74°7	78°7	83°3	87 2
A	16,006	14,750	13,370	12,794	12,188	11,620	11,201	10,870
B	2°4	2°47	2°46	2°44	2°44	2°45	2°41	2°41
C	15°7	14°2	13°6	12 5	12°2	11°6	10°6	10°2
W	16°58	15°28	14°02	13 6	12°6	12°03	11°5	11°2
F	1°6	1°46	1°35	1°27	1°21	1°16	1°12	1°10
D	246°07	233°9	214°75	195°0	191°5	181°	165°06	159°6
D'	4°58	3°89	3°57	3°25	3°19	3°12	3°0	2°66

RANKINE'S JACKETED CYCLE.

IDEAL CASE; $p_2 = p_3 = 2$; CONDENSING; $T_2 = 587°$.

Case V.

p_1	150	200	250	300	350	400	450	500
T_1	819°2	842°6	861°88	878°37	892°96	905°92	957°62	928°4
r	17°9	23°5	29°	34°4	39°9	45°3	50°76	56°1
V_2	52°89	52°89	52 89	52°89	52°89	52°89	52°89	52°89
H_1	858,289	863,843	868,411	872,323	875,794	878,890	881,707	884 197
U	215,400	236,900	251,555	264 900	—	284.560	291,855	295,600
E	21°3	23°3	24°5	25°5	25°8	26°7	27°3	28°2
M.E.P.″ . .	28°7	31°1	32°9	34°7	3	37°2	38 3	39°2
H_1'	995,526	1,013,915	1,040,650	1,040,806	1,055,534	1,060,938	—	1,072,853
A	12,177	10 920	10,595°3	10,000	11,162	9,520	9,318°9	9,155
B	2°30	2°29	2°28	2°27	2°26	2°25	2°24	2°23
B'	1 976	1°95	1°93	1°91	1°87	1°86	1°85	1°84
C	10°6	9°77	9°30	8°9	8°7	8°42	8°24	8°06
C'	9°22	8°39	7°87	7°45	8°24	6 99	6°75	6°71
W	12°6	11°38	10°77	10 35	—	9°85	9°76	9°60
F	1°21	1°092	1°05	1°0	—	°952	°944	°930
D	431	425	416°5	394	—	370	358	351
D'	7°97	7°39	6°94	6°57	—	6°0	5°96	5°86

RANKINE'S JACKETED CYCLE.

IDEAL CASE; $p_2' = p_3' = 16$; NON-CONDENSING; $T_2' = 677.35$.

Case VI.

p_1	150	200	250	300	350	400	450	500
T_1	819·2	841·63	861·88	878·37	892·96	905·92	917·62	928·42
r	6·36	8 32	10·32	12·58	14·21	16·15	18·02	20·0
V_2	18·84	18·84	18·84	18·84	18 84	18·84	18·84	18·84
H_1	795,894	801,600	806,171	810,084	813,585	816,666	819,234	821,988
U	129,240	143,698	166,529	178,878	181.054	198,365	206,734	211,150
E	14·8	16·9	18·2	19·25	20·0	20·9	21 5	22·1
M.E.P.' . . .	6,880	8,140	8 850	9,500	10,060	10,540	10,973	11,200
M.E.P." .	47·3	56·5	61·4	65	70·1	73·18	76·20	78·84
H_1'	881,868	903,990	912,666	930,750	940,878	950,445	958,241	964,840
A	17,370	15,111	14,411	13,200	12,710	12,096	11,798	11,500
B	2·49	2·47	2·46	2·45	2·43	2·42	2·41	2·40
B'	2·24	2·19	2·16	2 13	2·10	2·08	2·06	2·05
C	17	14·93	13·56	12·7	12·07	11·52	11·2	10·9
C'	15·35	13 0	12·54	11·05	10·9	9·98	9·57	9·32
W	17 8	15·64	14·48	13·6	13·07	12·8	12·2	11·9
F	1·77	1·46	1·398	1·32	1·27	1·20	1·18	1·16
D	267	243·1	230	208	197 8	188	180·2	177
D'	4·77	4·28	3·88	3·47	3·29	2·99	2·92	2·9

CONCLUSION.

En résumé, each standard has its peculiar use, thus:

(1) *The Joule Equivalent, taken as the absolute standard*, gauges the efficiency of the system in an absolute measure, and permits the comparison of the cycle with that of an imaginary perfect engine working between the initial temperature and the absolute zero, converting all heat supplied into mechanical energy, with efficiency unity. It enables us, by such a comparison, to ascertain the total magnitude of all wastes, thermodynamic or other, and the defects of the cycle chosen.

(2) *The Carnot Cycle, taken as a relative standard*, giving the magnitude of the efficiency of the so-called "perfect engine" between the limits of temperature of the case compared with it, permits a measure to be obtained of the wastes

other than the necessary thermodynamic losses, and fixes the limit of perfection of the real engine.

(3) *The Rankine Adiabatic Cycle, taken as a relative standard,* affords a means of similarly gauging the wastes of the engine, aside from those due the imperfection of the cycle, and measures the degree of perfection of the real engine of similar geometric cycle.

In making this comparison, the ideal cycle is made to correspond as closely as practicable with that of the real engine. It can be modified, if found desirable, by the introduction of the compression-line, in cases in which clearance and compression are important.

(4) *The Rankine "Jacketed-Engine Cycle,"* in the same way, measures the extra-thermodynamic wastes of the real jacketed engine, and gauges its approximation to the purely thermodynamic machine. In this case the real engine may be made to approximate the performance of the ideal comparatively closely.*

Each standard, absolute or relative, thus finds its appropriate place and purpose. The computed quantities in the tables which have been given, affording standards for special cases under each class, give measures of the efficiencies which the engineer must accept as limits toward which he may approach as he improves his engines, but which he can never fully attain.

* It is to be noted, however, that jacketing the ideal is ideally wasteful. The gain by the use of the jacket in practice is well understood to be due to the fact that it is a method of checking internal cylinder condensation, thus thermally gaining, usually, more than it itself wastes thermodynamically.

OBSERVATIONS ON MAGNETIZED WATCHES.*

By William T. Lewis,
Member of the Institute, President of the Horological Society of Philadelphia.

In this age of electricity and electrically-propelled machinery, the wearers of watches are constantly coming in contact with sources of danger to the fine time-keeping qualities of their vest-pocket companions.

Non-magnetic watches are those in which the balance-wheel, hair-spring, roller-table, lever and 'scape-wheel are made of metals which are neither magnetic nor diamagnetic; and such watches have been brought to a high degree of perfection, some having been produced which have had nearly as close a rate as the best of those which are not non-magnetic. In addition to this, several varieties of anti-magnetic shields have been placed on the market, which are said to be more or less effectual in preventing magnetism in watches.

However, it is of the ordinary watch (which is not non-magnetic) that I wish to speak to-night. In such a watch the hair-spring, roller-table, lever and 'scape-wheel are made of steel either wholly or in part. A watch of this kind will become magnetized by being brought into too close proximity to a powerful magnetic field, such as is developed in a dynamo or a motor; or by coming in contact with, or by being brought near to, an ordinary magnet; and there are also other sources of magnetic and electro-magnetic influence which will act injuriously upon a watch.

It will be seen that as all the steel parts of the watch become permanent magnets under the conditions mentioned each steel part thus assumes definite polarity and tends to place itself in a north-and-south position like a compass. Moreover, each steel part attracts and is attracted by, and repels and is repelled by, every other steel part in the watch.

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* Read at the stated meeting of the Franklin Institute, November 18, 1896.

The influence of these magnets, one on the other, and the influence of the earth's magnetism on the several parts, seriously impede their freedom of motion, thereby affecting the rate of the watch, sometimes even causing it to stop.

A simple method to detect the presence of magnetism in a watch is to place a small compass (one with a very fine sensitive needle about 0·8 centimeters in length) directly over the balance-wheel and upon the "bridge" which supports it. If the needle oscillates it is evident that the watch is magnetized. However, this test is not conclusive, as the

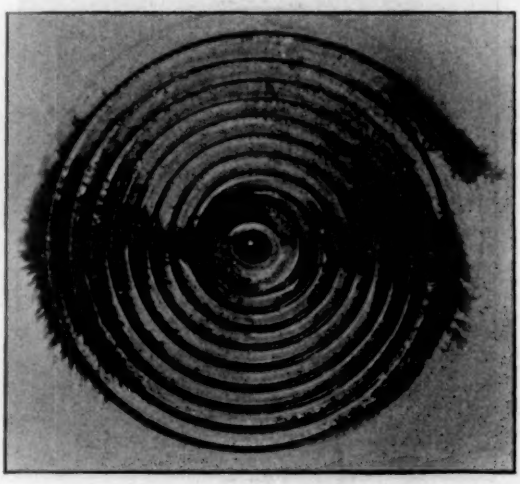


FIG. 1.

hair-spring may be magnetized, and, under certain conditions, the needle will not show it.

I am not aware that any one has yet called attention to the fact that the hair-spring or the main-spring of a magnetized watch contains "consequent magnetic poles," and I will endeavor to show that such is a fact, by means of the following experiments which I have made:

A hair-spring, which was placed in a powerful electro-magnetic field, was afterwards dipped in iron filings and photographed. The result is shown in *Fig. 1*.

On testing its polarity (to do which it was necessary to

straighten the hair-spring out into a long riband, similar to its condition before it was coiled into shape) it was found to contain numerous consequent poles, as shown in *Fig. 2*.

In a watch the outer end of the hair-spring is stationary, while the inner end is fastened to a collet which vibrates with the balance-wheel. As the balance-wheel makes approximately one and one-half revolutions at each vibration (*i. e.*, 270° on each side of the "dead center"), it is evident that at the moment when a watch becomes magnetized, the hair-spring will probably be at some other position than that of rest.

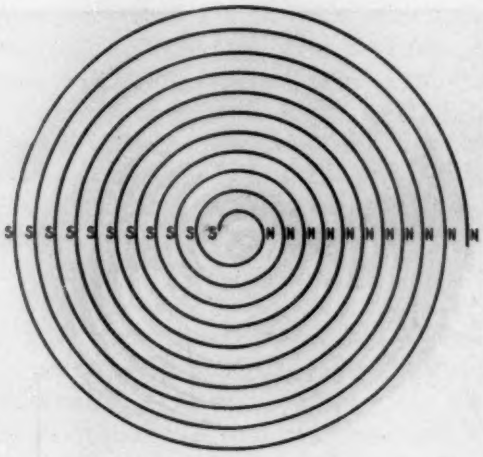


FIG. 2.

Fig. 3 shows a hair-spring which was magnetized when the balance-wheel had arrived at the end of its arc of vibration, and photographed (having been dipped in iron filings) after it had returned to its position of rest. The poles are not in the same straight line as in *Figs. 1* and *2*, as is shown by the iron filings grouping themselves in a different manner.

The polarity was found, on testing, to be as shown in *Fig. 4*, the dotted lines, passing through the poles, forming geometric curves.

Fig. 5 shows a form of demagnetizer in common use, which consists, essentially, of a helix *F*, switch or key *C*,

the commutator *A*, which serves the purpose of changing the polarity of the helix, and the flexible cord *E* to connect the machine with a battery or with an electric light circuit. If the current be alternating, the commutator can, of course, be dispensed with.

In operating with this machine the key is pressed down, and the commutator is turned by means of the crank *D* at a speed of about 150 revolutions per minute. The watch is then passed slowly through the helix, the speed of the crank being kept uniform in the meantime.

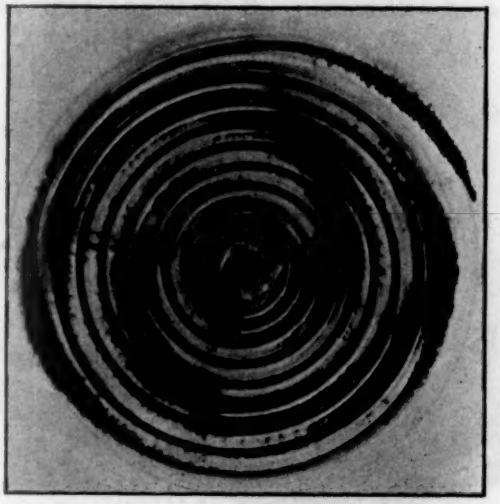


FIG. 3.

With the ordinary demagnetizer the hair-spring of a watch is very difficult (if not impossible) to demagnetize without treating it separately, as it possesses about four times as many magnetic poles as it contains coils. The poles are difficult to locate, as the coils are not more than 0·15 millimeters to 0·25 millimeters apart in watches of the usual size. The whole diameter of the spring may be from 5 millimeters to 8 millimeters.

Then, also, the vibration of the hair-spring under the action of the demagnetizer seems to prevent the proper demagnetizing effect from being produced.

Good results, however, can be secured by placing the hair-spring on a watch-glass and covering it with very viscous oil or with a drop of melted beeswax, and placing it in that condition under the action of the demagnetizer, keeping the watch-glass horizontal and, at the same time, causing it to revolve about its center. The oil or wax can afterwards be dissolved in benzine and the hair-spring cleaned.

Demagnetizers of various construction have been contrived; but I do not know of any which will *thoroughly* demagnetize all the parts of a watch *unless the watch be taken apart* and each steel piece submitted separately to the action

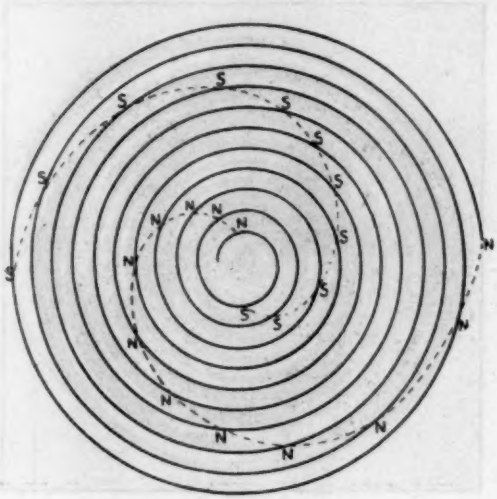


FIG. 4.

of the demagnetizer, testing each piece each time it is passed through the machine in order to ascertain to what extent the magnetism has been removed, and again passing it through the helix in another position if it be found to still contain magnetism.

If, in passing the watch through the helix (without taking it apart), any steel part be so situated in the watch, and be also magnetized in such a manner that its magnetic axis be *otherwise* than parallel to the axis of the helix, it will be seen that such part will not be thoroughly demagnetized.

Fig. 6 shows a view of the helix, in section. The hands of the watch denote the hour of 9 o'clock. If, before the watch was passed through the demagnetizer, one end of the minute-hand was a north-seeking pole, and the other end a south-seeking pole, it is evident that the minute-hand will now be demagnetized.

But to demagnetize the hour-hand, the watch would need to be turned so that the magnetic axis of the hour-hand would be parallel to the axis of the helix. There is also the steel arbor which carries the hands, the axis of which is at right angles to the planes in which the hands

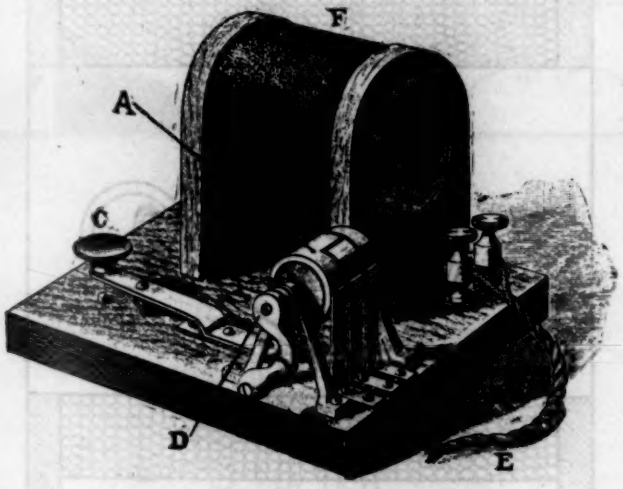


FIG. 5.

lie. Then there are other steel parts which lie in other planes; so that it would seem necessary to cause the watch to revolve in such a manner that every plane shall be subsequently brought into a position parallel to the axis of the helix.

To this end I am now constructing a demagnetizer, which I may have the opportunity of exhibiting at some future meeting; but which I will now describe in order that I may have the advice of others better versed in the mysteries of electricity and magnetism than myself.

In *Fig. 7*, *A* is a watch to be demagnetized, mounted on a

circular disk *B*, being held in position by the clutches *C C*, and a third clutch which is not shown. The disk is caused to revolve by the bevel gears *E E'*, which receive their motive power from the gear *G*. The gear *H* is stationary; while the frame *K K'* is mounted on the revolving shaft *L*, driven by the bevel gear *M M'*, which in turn is caused to revolve by a belt from a pulley *N*, on the shaft *O*, to the pulley *P*, on the shaft *Q*, of the small motor *R*, which is driven by the battery *S*. This motor will be enclosed in an

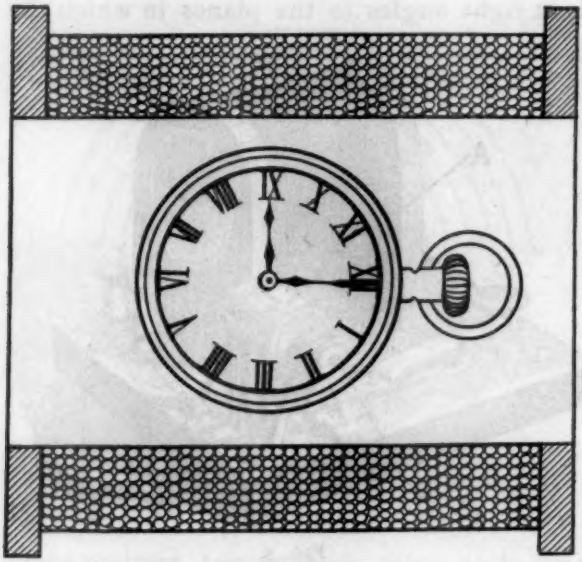


FIG. 6.

iron cylinder to insulate it magnetically, and so prevent its influence on the watch. A clock-work could, of course, be used instead of the motor. The head of the carriage is shown separately in *Fig. 8*.

It will be seen that the revolving of the frame *K K'* around the axis of the shaft *L* will cause the gear *G* to revolve around the gear *H*. At the same time the revolving of the gear *G* on its own axis will cause the disk *B* to revolve around its own center.

Thus the watch will revolve around its vertical axis (*i. e.*,

the axis of the shaft *L*) and around its horizontal axis (the axis of the shaft *D*) at the same time. By having one tooth more (or less) in the gear *G* than in the gear *H*, the watch

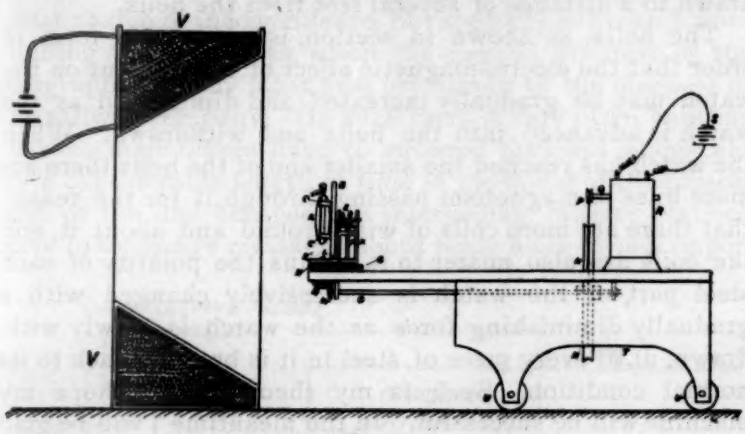


FIG. 7.

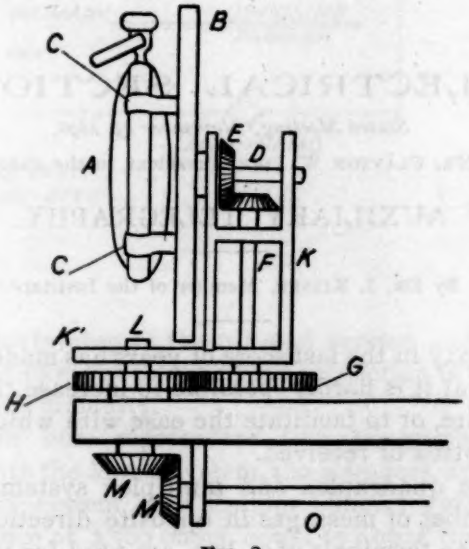


FIG. 8.

will be continually placed in new and different positions, until the gears *G* and *H* arrive in the same relative positions in which they were at the start.

The carriage *7* is mounted on wheels *U U'*, in order that the watch may be slowly advanced into the helix *V* to its smaller end, and again slowly withdrawn. It should be withdrawn to a distance of several feet from the helix.

The helix, as shown in section, is given this form in order that the electro-magnetic effect of the current on the watch may be gradually increased and diminished as the watch is advanced into the helix and withdrawn. When the watch has reached the smaller end of the helix there are more lines of magnetism passing through it for the reason that there are more coils of wire around and about it, and the coils are also nearer to it. Thus the polarity of each steel part of the watch is successively changed with a gradually diminishing force as the watch is slowly withdrawn, until every piece of steel in it is brought back to its normal condition. Such is my theory, and I hope my machine will be successful. In the meantime I will be glad to receive any suggestions.

ELECTRICAL SECTION.

Stated Meeting, November 25, 1896.

MR. CLAYTON W. PIKE, President, in the chair.

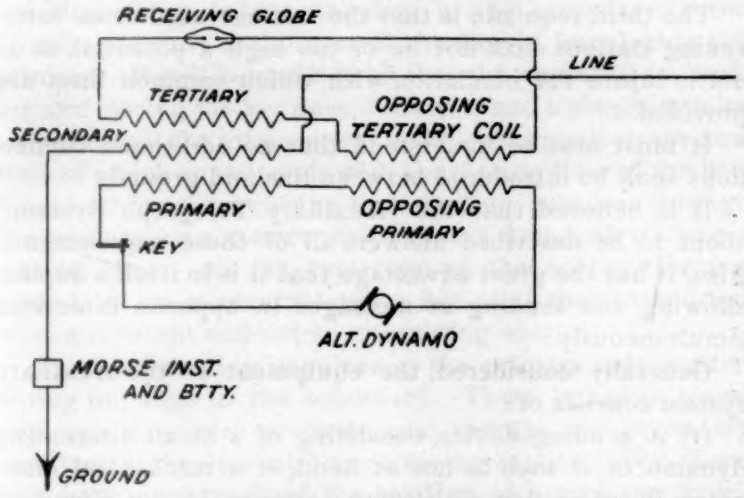
AUXILIARY TELEGRAPHY.

By DR. I. KITSEE, Member of the Institute.

Telegraphy in the last score of years has made such rapid progress that it is hardly possible to increase the capacity of a line wire, or to facilitate the ease with which messages are transmitted or received.

We have quadruplex and multiplex systems. We can send a number of messages in opposite directions; but we cannot, if the terminals of a line are used for transmitting or receiving one kind of messages, transmit messages from and to intervening stations of such line without interfering with the telegraphic communications of the terminal offices.

And the lack of a system permitting communication between intervening stations, at one and the same time, when the line is being used by the terminal offices, is generally a great source of inconvenience, but specially so on such lines running along railways, where the general business of the telegraph company must give preference to the business of the railway company. On such lines it very often happens that the main offices have to suspend business altogether for a considerable length of time in the midst of the busiest part of the day because the intervening railway stations have to exchange messages about some more or less impor-



tant point pertaining to the railroad service, and the device as presented to-night to your kind inspection is designed to overcome this difficulty.

We have here represented two telegraphic stations equipped with the Morse system, the sounders, and also with the Auxiliary system, both stations joined together through wire-resistance of 2,500 ohms, equal to about the resistance of the ocean cable. The diagram shown herewith will illustrate the instruments used, as well as the electrical connections of same, and the gentleman assisting me will, as the evening progresses, send and receive messages over this

line with the aid of the auxiliary device, as well as the Morse, and the ease with which such messages are simultaneously transmitted will, no doubt, be apparent to you.

The first requisite of such device to be worked from intervening stations at one and the same time, when the line is used by terminal stations, is that there shall not be inserted in the line large resistance or batteries, or other generators of electricity which may come in conflict with the batteries of the terminal stations.

The second requisite is that the current transmitted from the main stations shall not actuate the receiving or sending instruments of intervening stations, and *vice versa.*

The third requisite is that the current used from intervening stations shall not be of too high a potential, so as not to injure the insulation with which common lines are provided.

It must also be understood that no additional connections shall be introduced between line and ground.

It is believed that the "Auxiliary Telegraph System" about to be described answers all of these requirements. Also, it has the great advantage that it is in itself a duplex, allowing the sending of messages in opposite directions simultaneously.

Generally considered, the equipment of the Auxiliary system consists of:

(1) A sending device, consisting of a small alternating dynamo, or, if such be not at hand, of a mechanical alternator, in connection with some batteries in the circuit, in which is placed a sending key and the primary of a convertor.

The secondary of this convertor is connected in series with the line, and the tertiary of this convertor is locally connected with the vacuum globe, which acts as a receiver.

The primary, as well as the secondary of the convertor, should be a low-resistance one. The tertiary coil should be wound in such manner as to increase the E.M.F. to an extent necessary for producing the glow in a vacuum globe.

Each of the stations, the sending as well as the receiving station, is also provided with a second primary, connected in series with the first primary. This second primary is

placed into a coil equal in its inducing capacity to the tertiary first spoken of. The terminals of this coil, which I call the second or opposing tertiary, are connected in opposition to the first coil with the receiving vacuum globe.

This second series of coils is necessary for the duplexing of the system.

Following is a short description of the mode of sending messages according to this—the Auxiliary system:

At the sending station, the operator connects his first primary coil through his sending key with the source of electricity. With the aid of this key he sends through his primary coil currents of electricity. These impulses, which are alternating, induce impulses in the secondary, corresponding in time to the time of the flow of impulses in the primary. It will be understood that the operator, in opening and closing the key once, does not send a single impulse only through the primary, but a series of impulses, the flow time of which corresponds with the closing time of the key, a dot with its short closing time sending impulses through the primary for a shorter period than a dash with its longer closing time. As far, therefore, as the operator is concerned, he has to manipulate the key as if the current-flow were a constant and not an alternating one.

These alternating impulses in the primary induce alternating impulses in the secondary. These impulses travel over the line, wire or cable, and through the secondary inserted in the line at the receiving station. We, therefore, have, as a result of the sending of a message travelling over the line rapidly alternating impulses of such short duration that the other, *i. e.*, Morse or similar sending or receiving instruments, depending, as they do, on the movement of the armature of an electro-magnetic device, cannot respond and remain practically unaffected by the flow of these impulses. As around each of the secondary coils, sending as well as receiving station, the tertiary coil is wound, it follows that the alternating impulses, travelling through the secondaries, will induce alternating impulses in the tertiaries, and as the coils are wound to the necessary high potential, the generated tertiary impulses

will, if the terminals of the coils are connected to a vacuum tube or device similar in its action, produce in said tube or similar device a glow, corresponding in time to the time of the electric impulses generated through induction—shorter glow-time for dot and longer glow-time for dash.

The office and function of the second primary coil has, so far, not been taken into consideration, and if this system is used only as a simplex one, then the addition of this coil is not necessary; but as set forth above, the object is to con-triplex or duplex the auxiliary of telegraphy, and the prime conditions to be fulfilled in practically carrying out of the method of simultaneous transmission in opposite directions are:

(1) That the receiving instrument at the home station shall remain entirely unaffected by the movements of the transmitting key at that station, while at the same time it shall remain free to respond to the currents transmitted by the key at the distant station.

(2) If this induced system shall be used in conjunction with the usual receiving and sending instruments, which are liable to be opened just at the time of transmission with induced currents, that the same currents shall always be provided with an uninterrupted passage to the ground, at the home station as well as at the distant station.

To fulfil the first condition, is the office and function of the second primary coil. This coil is so wound or connected to the source of current that the alternating impulses flowing through it are capable of inducing in the second tertiary coil impulses of opposite direction from the impulses induced through the action of the secondary coil in the first tertiary.

The necessary adjustment of the inducing influence of one coil on opposing coil can be accomplished:

(1) Through the operation of a rheostat, through the action of which more or less resistance can be thrown into the circuit of the second primary; or,

(2) The second primary can be partially withdrawn from the inner space of the second tertiary.

Supposing now, the adjustment being perfected, the

operator at one station is transmitting a message to the second station.

In depressing his key he sends a multitude of impulses through the primary, inducing thereby a multitude of impulses in the secondary, which multitude of impulses will induce tertiary impulses in the tertiary coil, and will flow over the line into the secondary of the second station, inducing impulses in the tertiary of the receiving station.

Ordinarily, the receiving instruments of both stations, the receiving as well as sending, would answer; but as the depression of the key at the sending station also sends, simultaneously with the sending of the impulses through its first primary, impulses starting at the same time and at the same frequency through its second primary, and as the inducing effect of such impulses is opposite from the induced impulses flowing through its first primary, it follows that both the influence of the first and second primaries on its tertiary are neutralized, and that therefore the receiving instrument at the sending station will not respond.

The proviso of an uninterrupted passage for the induced current is fulfilled by shunting the key and instrument of the Morse, or similar devices, through a condenser.

As stated in the introductory remarks, the alternating current flowing over the line is of such low potential that it would not affect or injure the insulation of a submarine cable, and it is believed that it can be used with impunity on cables as well as land lines.

In conclusion, it can be said that the tests of the chief electrician of one of our foremost telephone companies have established the fact that the leakage and induction from a line traversed by the currents of the auxiliary are not greater than the leakage and induction from a wire traversed by a telephonic current, and that, therefore, the application of this system to existing submarine cables is believed to be a practical one.

[NOTE.—During and after the reading of the paper, Mr. W. B. Eldridge operated the system by sending and receiving messages on both the Morse and Auxiliary at one and the same time over a single line-wire.—ED.]

NOTES AND COMMENTS.*

TWENTY-FIFTH ANNIVERSARY OF THE STEVENS INSTITUTE OF TECHNOLOGY.

A noteworthy event in the annals of technical education in the United States will be the forthcoming celebration of the twenty-fifth anniversary of the Stevens Institute of Technology, on the 18th and 19th of February next.

The festivities will consist of a banquet, at the Hotel Waldorf, New York, to which representative engineers and technical educators throughout the country will be invited. On the following day the Institute will be open for inspection, and the methods of instruction, together with the apparatus in the various laboratories, will be explained.

Not the least interesting feature of this exhibition will be the collection illustrating the work of the alumni, and consisting of machinery, apparatus, drawings, etc., representing the product of their activity during the twenty-five years.

The festivities also include a reception, tendered to the faculty, graduates and undergraduates, by Mrs. E. A. Stevens, widow of the founder of the Institute, at Castle Point, Hoboken. A promenade concert and dance in the evening will conclude the celebration.

The Stevens Institute of Technology was founded by the late Edwin A. Stevens, of Hoboken, N. J., and in 1870 the erection of a building was commenced by the trustees, Mrs. E. A. Stevens, Mr. S. Bayard Dod and Mr. W. W. Shippen. Dr. Henry Morton, at that time Secretary of the Franklin Institute, of Philadelphia, was tendered the presidency of the Institute, and gathered a faculty of eight members about him. To this number others have, from time to time, been added as the work of the Institute increased, until at the present time the faculty includes twenty-two professors and instructors. The total number of student graduates is 675, and the number in attendance during recent years has been about 260 each year.

The Stevens Institute has always taken high rank among the institutions devoted to technical education in the United States, and its twenty-five years of successful effort is amply exemplified in the work accomplished by its graduates in all departments of mechanical and electrical engineering.

THE EXPLOSIVE PROPERTIES OF ACETYLENE.

Progressive Age prints the following abstract of some experiments recently completed by Messrs. Berthelot and Vieille, which show that considerable precautions are necessary in dealing with acetylene, particularly in the compressed state. The gas in question is an endothermic body—that is to say, a

* From the Secretary's monthly reports.

quantity of heat is liberated on decomposing it into its constituents, hydrogen and carbon. Reasoning on this basis, the experimenters determined to try whether the gas could not be detonated by means of a cap of fulminate of mercury. This proved possible, though at atmospheric pressures the explosive wave did not proceed throughout the body of the gas, the decomposition being limited to the immediate neighborhood of the detonation. When, however, the gas was compressed, the experiments showed that it might prove a dangerous explosive. In fact, it was not then necessary to use a detonater, as it was found that the mere heating of the gas by an incandescent platinum wire was sufficient to cause an explosive decomposition of the acetylene. Average figures from a number of experiments, made with different degrees of initial compression showed the following rises of pressure:

Initial Pressure. *Pounds per Square Inch.*	*Maximum Pressure Observed on Explosion.* *Pounds per Square Inch.*	*Ratio.*
31·7	138·7	4·4
49·4	271·0	5·5
85·1	600·0	7·0
160·0	1,312·0	8·2
301·0	3,028·0	10·1

On opening the steel test tube after an experiment, it was found to be filled with a mass of finely divided carbon agglomerated together by the increase of pressure. The rise of temperature at the moment of explosion was considerable, and in the case of the last of the experiments, referred to above, amounted to as much as 2,750° C. It was, moreover, found possible to detonate liquefied acetylene in the same way, a pressure of over 35 tons per square inch being then attained. The explosion was started, as in the previous cases, by means of a white-hot platinum wire. Dropping a bottle of the liquefied gas, or allowing a heavy ram to fall on it, proved insufficient to detonate the mixture, although when the bottle was broken by the ram a violent explosion occurred. This, however, arose from the combustion of the gas, and thus differed materially in nature from the experiments previously made, in which the acetylene was merely resolved into its elements.

LUCIUM, A NEW ELEMENT.

From London *Nature* we learn that, in the course of researches on monazite sand, M. P. Barrière appears to have come upon a new elementary body, to which he has given the name *lucium*, and which he purposes using for the production of an incandescent gas light similar to that of Auer von Welsbach. Careful investigation has been made of the new and independent character of lucium, in order to prove that its use was not anticipated by the Welsbach patents. The examination showed that while the salts of cerium, lanthanum and didymium form with sodium sulphate insoluble double salts, lucium does not. Thorium and zirconium form insoluble double salts with potassium sulphate; this is not the case with lucium. Yttrium, ytterbium and erbium are not precipitable by sodium thiosulphate, whilst lucium chloride is

precipitable. From glucinium, lucium differs, as its salts are precipitable by oxalic acid. The lines in the spectrum of lucium are special, and only approximate slightly to those of erbium. Erbium oxide, on ignition, appears of a very pure rose-color, and its nitrate is red. On the contrary, lucium oxide is white, slightly grayish, and its nitrate is white. The aqueous solutions of the erbium salts are red or rose-color; those of lucium, even if containing 15 or 20 per cent. of the salt, are almost colorless. These and other reasons seem to show that lucium is a new distinct elementary body. Its atomic weight has been calculated as = 104.

PRODUCTION OF AMBER.

The working of amber in Prussia is a monopoly in the hands of a firm which owns the best two mines, Palmnicken and Kraxtepelle. For the concession the firm, according to Consul Hunt, of Dantzig, pays to the German Government a royalty of 650,000 marks (about $162,000) a year. It is reckoned that this firm has up to now paid no less a sum than $5,000,000 in royalties to the German Government. In addition to the output from the mines in 1895, a good deal of amber was picked up on the beach at Pillau, in the province of East Prussia, being washed up with the seaweed during the prevalence of northwesterly gales. The shore at Pillau after a storm is sometimes covered with a layer of seaweed 3 feet thick, among which the amber is found entangled. Men, women and children find easy and lucrative employment in searching for the amber along this part of the amber coast. The people engaged in this precarious work often earn 30 shillings a day and more. In 1895, about 100 tons of raw amber came to Dantzig to be worked up, as compared with 140 tons in 1894. It was nearly all melted to make lac and varnish. The larger pieces are made into beads, which are sent all over the world. The beads known to the trade as Leghorn corals were in strong demand.—*Scientific American.*

ACETYLENE.

From the *Progressive Age*, we take the following data bearing on the behavior of acetylene, which are credited to the investigations of M. Brevans:

"If ordinary acetylene from carbide be passed through a series of three washing-flasks containing a solution of sulphate of copper, there is no effect perceptible within three hours; but after twelve hours the first flask contains a black-brown, brilliant precipitate, the quantity of which goes on increasing for as much as eight days. This precipitate explodes on shock, friction or heating; and it appears to be a mixture of phosphide and silicide of copper, of sulphate of cupro-acetyle, and a variable quantity of acetylide of copper. Its production appears to depend largely on the presence of ammonia in the crude acetylene gas; and it shows that the crude acetylene contains phosphoreted hydrogen and siliciureted hydrogen. The second flask contains a precipitate which is similar in appearance, but less explosive; and the precipitate in the third flask is not explosive. The explosive precipitate in the

first flask will explode even under water, as, for example, when we try to rub it off the glass with a glass rod.

"As to the explosibility of acetylene there are two opinions: one, that there may be metallic acetylides formed, which act as detonators to the acetylene itself, so that acetylene cannot be used with reservoirs which are capable of being attacked by it; the other, that it can only be exploded when mixed with air, and that the influence of the outside explosions which can set it off cannot travel far through air. In any case, acetylene, at a pressure not much exceeding that of the atmosphere, is not explosive, though it is explosive at pressures above 2 atmospheres; so that there is no reason to fear an explosion through flame running back to a reservoir under a very small excess of pressure. Shock alone does not appear to cause explosion of the gas, only of the acetylides. The alleged poisonousness of acetylene—which has not, as yet, given rise to any accident—would appear to be due to the occasional presence of cyanogen compounds, and is not a feature of pure acetylene. The presence of sulphureted hydrogen in acetylene seems to depend on that of sulphide of aluminum in the carbide of calcium; sulphide of calcium may exist in it without forming this impurity. The blocking of gas jets by acetylene flames seems to be due to the formation of phosphoric acid. If oxygen be not present, acetylene does not attack copper; the oxide must be formed before the acetylide can be produced."

ENGINEERING NOTES.

A means for *preventing the noise made by trains* in passing over iron bridges has been devised by a German engineer named Boedecker. He puts a decking of 1¼-inch planks between the cross girders, resting on 3-inch timbers laid on the bottom flanges. On the planks a double layer of felt is laid, which is fixed to the vertical web of the cross girder. At the connections with the girder a timber cover joint is placed on felt, and two hooked bolts connect the whole firmly to the bottom flange. Four inches of slag gravel cover the decking, which is inclined toward the center of the bridge for drainage purposes. A layer of felt is laid between the planks and the timbers they rest upon, and the iron work in contact with decking and ballast is asphalted. The decking weighs 600 pounds per yard for a bridge 11 feet wide, and costs 23 cents a square foot. It is water-tight, and has proved very satisfactory in preventing noise.

BOOK NOTICES.

Tables Showing Loss of Head Due to Friction of Water in Pipes. By Edmund B. Weston, C.E., Member of the American Society of Civil Engineers, Member of the Institution of Civil Engineers of Great Britain. New York: D. Van Nostrand Company, 23 Murray and 27 Warren Street. 1896. Price, $1.50.

The author here presents two tables of flow in pipes, one referring to pipes with very smooth inner walls, such as lead and brass pipes, from ½ inch

to 3 inches diameter, and the other referring to new cast-iron pipes, from 4 to 60 inches diameter.

The tables give the velocity, entry and friction heads and the discharge in gallons per minute and per twenty-four hours, corresponding to velocities covering a considerable range.

The velocity heads are, of course, calculated by the simple formula:

$$h_v = \frac{v^2}{2g},$$

and the entry head by the formula,

$$h_e = 0{\cdot}505\,\frac{v^2}{2g}.$$

In Table 1, the friction head is calculated by the author's formula,

$$h_f = \left(0{\cdot}0126 + \frac{0{\cdot}0315 - 0{\cdot}06\,d}{\sqrt{v}}\right)\frac{l}{d}\,\frac{v^2}{2g},$$

published in *Transactions* American Society of Civil Engineers, Vol. XXII, 1890, while in Table 2, covering new cast-iron pipes, the two formulas of Darcy,

$$h_f = \left(0{\cdot}017379 + \frac{0{\cdot}0015965}{d} + \frac{0{\cdot}0040723 + \frac{0{\cdot}000020816}{d^2}}{v}\right)\frac{l}{d}\,\frac{v^2}{2g},$$

$$h_f = \left(0{\cdot}0198920 + \frac{0{\cdot}00166573}{d}\right)\frac{l}{d}\,\frac{v^2}{2g},$$

are used; the former for velocities less than 0·33 foot per second, and the second for greater velocities.

In Table 1 the friction head is given for 100 feet length of pipe, and in Table 2 for 1,000 feet.

The author, being unable to discover a general formula which would satisfactorily apply to old cast-iron pipes whose walls had become roughened by oxidation, has given a series of coefficients, corresponding to different ages of pipe in years, for use in connection with Table 2.

It will at once occur to engineers that, under certain conditions, cast-iron pipes will sometimes corrode more in two or three years than, under other conditions, in twenty or thirty years; and that it must, therefore, be hazardous to depend upon a table in which the effect is assumed to be proportional merely to the age of the pipe.

For some reason, the columns in the tables are arranged without any apparent controlling idea. The column of mean velocity is, of course—and necessarily—placed first; but then, instead of grouping the three heads together and the two rates of discharge together, we have: first, velocity head; then, discharge in gallons per minute; then, friction head; then, discharge in gallons per twenty-four hours; and, finally, the entry head. T.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, December 16, 1896.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 16, 1896.

JOSEPH M. WILSON, President, in the chair.

Present, 133 members and visitors.

Additions to membership since last report, 10.

The following nominations were made in pursuance of Article VI of the By-Laws:

President	to serve one year, ...	JOSEPH M. WILSON, JOHN BIRKINBINE.
Vice-President	" three years, ...	W. P. TATHAM.
Secretary	to serve one year, ...	WM. H. WAHL.
Treasurer	" " " , ...	SAMUEL SARTAIN.
Auditors	" three years, ...	W. O. GRIGGS.
	To serve for the unexpired term of Samuel H. Needles, deceased, . .	JOHN H. COOPER.

Managers (to serve three years).

GEORGE E. BARTOL,
ARTHUR BEARDSLEY,
HENRY C. BROLASKY,
JAMES CHRISTIE,
F. L. GARRISON,
H. W. JAYNE,
LAWRENCE T. PAUL,
HORACE PETTIT,
JOSEPH M. WILSON.

Committee on Science and the Arts (to serve three years).

WM. M. BARR,	JOHN HAUG,	LOUIS E. LEVY,
H. F. COLVIN,	WM. C. HEAD,	D. ANSON PARTRIDGE,
THOS. P. CONARD,	WM. C. HENDERSON,	TINIUS OLSEN,
SPENCER FULLERTON,	H. R. HEYL,	SAMUEL P. SADTLER,
J. M. HARTMAN,	G. A. HOADLEY,	PAUL A. WINAND.

Vacancies on the Committee of Science and the Arts were filled by the election of A. Langstaff Johnston for the unexpired term of Wm. McDevitt, resigned, and Edgar Marburg for the unexpired term of Wm. N. Jennings, resigned.

Under a suspension of the rules, Prof. F. L. Garrison presented the following preamble and resolution, and spoke in support of them, urging that both the time and opportunity were favorable to the carrying out of the proposed enterprise :

"WHEREAS, the Franklin Institute, for several years, has been desirous of holding a public exhibition, but has been unable to do so, principally because of the want of a building of suitable character and location, available for the purpose ; and

"WHEREAS, it appears that the Franklin Institute, at this time, has the opportunity of securing, on favorable terms for such purpose, the use of the large building about to be erected at Eleventh and York Streets, Philadelphia, by the United Singers of Philadelphia, for the eighteenth annual Sængerfest, to be held in June, 1897; therefore,

"*Resolved*, That the Board of Managers of the Franklin Institute be requested to give the matter their prompt and earnest attention, with the view (should it be found feasible and expedient) of making the necessary arrangements for obtaining the use of this building, for holding a public exhibition therein, in the autumn of 1897."

The preamble and resolution were seconded by Mr. G. M. Eldridge, who strongly advocated their passage.

Prof. E. L. Elliott, of Pittsburgh, presented a paper on "The Utilization of Artificial Light." The paper treated the subject partly from the historical point of view, but chiefly with reference to the question of the proper method of securing the most efficient distribution and diffusion of the light. The practical solution of this problem by means of the "Holophane Globes," invented by Blondel and Psaroudaki, of Paris, was made the subject of an interesting demonstration.

Mr. C. Francis Jenkins, of Washington, read a paper describing his lately-devised "Phantoscope," an apparatus designed for exhibiting a series of rapidly-shifting photograph transparencies, so related to one another as to give the impression of objects in motion. At the close of his remarks, the speaker gave a demonstration of the apparatus arranged in connection with a projecting lantern.

Mr. N. Howland Brown exhibited an improved Acetylene Gas Machine, and gave a demonstration of the comparative value of this gas as an illuminant for lantern projections. The demonstrator exhibited the fact that acetylene gave nearly as bright a field as that afforded by the lime light with oxy-hydrogen gas.

On motion of Mr. Heyl, the three subjects above enumerated were referred to the Committee on Science and the Arts for investigation and report.

The Secretary in his monthly report, called attention to a very instructive exhibit illustrating the manufacture of the lately discovered compound known as "Carborundum," now largely employed in the arts as an abrasive material. He also exhibited and commented on a novel metallic flexible tube, devised by Mr. T. R. Almond, of Brooklyn, N. Y.

Adjourned.

WM. H. WAHL, *Secretary.*